University of Edinburgh.

THESES PRIZE COMPETITION.

Thesis by D. Murray Lyon

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THE VISCOSITY OF THE BLOOD.

a Thesis

for the degree of M.D. 1920.

by

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EX BIBL. UNIV. EDINBURGEN.

TABLE OF CONTENTS.

My attention was first directed to this subject by the late Professor Greenfield, when, as Stark scholar in Clinical Medicine, I sought his advice as to a suitable line of research. He was specially interested in blood viscosity from the point of view of its possible relation to blood pressure and the production of disease of the circulatory system. An examination of the literature shewed that opinions on essential points varied widely, and it was obvious that a wide survey of the subject was necessary before such a relationship could be fully appreciated.

The following Thesis embodies the results of my investigation.

For access to most of the cases I am indebted to Professor Greenfield, but many of them were seen in other medical wards of the Infirmary as well as in the Royal Hospital for Sick Children, and the Maternity Hospital.

SCOPE OF THE WORK.

In order to make a comprehensive study of Blood Viscosity I drew up the following scheme of observations to be recorded in all cases.-

Name, age, and sex of patient.
Date, time of day, and hour of last meal.
Temperature, and state of the weather.
Diagnosis, and duration of the disease.
Viscosity reading.
Blood examination - R.B.C., Hb., and W.B.C.
Blood pressure estimation, with note of the condition of the vessel wall and the thickness of the patient's arm.
The temperature, pulse and respiration rate.
Amount of exercise taken by patient.
Presence or absence of perspiration, oedema, cyanosis.
Quantity of urine passed in 24 hours; abnormal constituents etc.
State of the bowels.

In special cases the alkalinity, specific gravity and coagulation time of the blood, were also examined.

These/

These facts were entered on index cards to facilitate comparison of various factors. A brief abstract of the history, etc., was entered on the reverse of the card.

Upwards of 500 cases were examined - many of them several times. At first, attention was directed to normal cases, then later to various conditions of disease. Many types of illness were included in this survey, but experience soon shewed from which cases most information was to be gained, and special attention was given to these.

In addition to this, a good deal of laboratory work was done on the factors influencing the taking of the blood and the working of the instrument, and on the share of the various blood elements in producing viscosity.

THE VISCOSITY OF THE BLOOD.

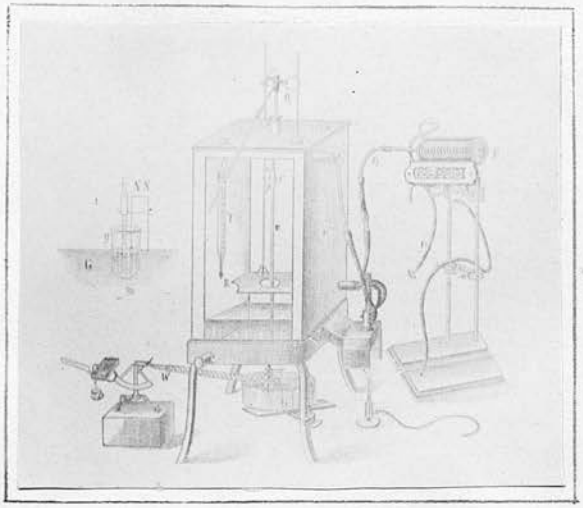
The blood normally is about five times as thick as water and in health varies but little from this figure. Wide differences, however, may appear in disease, my highest reading - 24.25 (in a congenital heart case with polycythaemia) being more than sixteen times greater than the lowest - 1.50 (the reading in a case of pernicious anaemia, where the blood was little better than plasma.) This consideration at once shews how extremely important the viscosity of the blood is, in the economy of the body. It is of especial importance in the physics of the circulation, for the speed of the blood varies inversely, as its thickness, and the amount flowing through a given organ depends on the same factor. Other things being equal, an alteration in the viscosity will increase or diminish the amount of work the heart is called upon to perform. It has been shewn that in a system of tubes the thickness of the flowing blood controls the pressure (Bayliss 1916), hence blood viscosity must be an important factor in maintaining the blood pressure. Such considerations have led Hirsch and Beck (1901), Cheinisse (1910), Allbutt (1898) and Lauder Brunton (1914) to believe that increased viscosity may be one of the important causes/

causes of cardiac hypertrophy, and of arterial degeneration.

The blood viscosity is a physiological constant, just as the temperature and the pulse rate are, and it is probable that the body can compensate for even considerable alterations of the viscosity by addition or abstraction of water, as well as by changes in the lumen of the blood channels. Under diseased conditions, as in nephritis, these reserve powers may be seriously impaired so that the body can no longer keep the blood viscosity at its proper level.

The thickness of the blood also governs the rate of metabolic exchange between the blood and the tissues and so is of great importance in the normal functioning of the organs. Increased viscosity diminishes the speed of diffusion between the dissolved salts although the osmotic tension remains the same (Mayer 1901). Hence the thickness of the blood will to some extent protect the red corpuscles against haemolysis. The blood viscosity probably produces modifications in the renal filtration.

Several of these points have been confirmed by animal experiments. Heffter in 1892 first noticed the importance of the degree of viscosity in the fluid he employed for perfusion of the heart. Albanese (1893) shewed that the perfusing fluids ought/



TROMMSDORFF'S APPARATUS.

ought to be isoviscous as well as isotonic with the normal blood. Similar observations were made by Trommsdorff (1901).

Heubner (1905) shewed that the electrical reaction of a rabbit's muscle depended on the viscosity of the fluid. He also noted that an isoviscous and isotonic gum solution washed out of the vessels of an animal more readily and quickly than normal saline alone.

Roger (1908) found that when perfusing the vessels of a newly killed animal, much fluid escaped into the tissues if Locke's solution was employed, but that the addition of a suitable amount of gum prevented this occurring.

Several authors, especially in later years, (Brück 1910, Ochlecker 1910, Simon 1911 and Susenguth 1912) have recommended viscosity examination as an aid to diagnosis and prognosis in acute abdominal conditions. They believe that by its use they can differentiate internal haemorrhage from appendicitis and in the latter disease can even tell how much of the peritoneum is involved.

Bachmann (1909) speaks of its importance as a diagnostic between pneumonia and typhoid, while Csépai and Torday(1911) claim that they have discovered a method based on viscosity examination, for/

for diagnosing tuberculosis.

In concluding his review of the subject, Clifford Allbutt remarks.- "If as yet the estimation of viscosity be of little clinical service, it is desirable notwithstanding, that academic observations on the subject should still be persued, seeing that it is concerned with those dynamical problems of molecular constitution, osmotic pressures, electro-conductivity and chemical physics on which life depends." And again - "If the viscosimeter cannot become a handy clinical instrument, yet the clinician must demand from the physiologist some approximate calculations of the potent, if not dominant factor of viscosity." This question I have set myself to solve.

H I S T O R I C A L.

Considering the importance of the subject it is curious that until recent years it should have received so little attention. This, Martinet (1912) attributes to two causes, the lack of an instrument suitable for clinical investigation, and the contradictory results obtained by the earlier observations. In addition to this, coagulation of the blood prevented extended clinical examinations.

The earliest investigator to turn his attention to the subject was Stephen Hales, who in 1733 published in his "Statical Essays" (p. 47) an account of his observations on the thickness of the blood. He introduced different solutions into the aorta of dead dogs under constant conditions of pressure and observed the amount and rate of outflow from the cut capillaries of the mesentery and noticed that the greatest resistance to flow, was met in the smallest vessels.

Nothing further appears to have been done for more than a century, when Poiseuille took up the subject. Attracted to the investigation as a physiological problem, he carried out such elaborate and careful experiments that his work has remained the/

the standard on which physicists have based all subsequent investigations. In 1843 he published an account of experiments where various salt solutions were perfused through the vessels of a frog and through glass tubes. The results did not tally well (since the solutions were neither isoviscous nor isotonic) and he adopted the simpler plan of examining the conditions influencing the flow of fluids in glass capillary tubes. He discovered the influence of temperature, pressure, and the size of the capillary on the "transpirability" of simple fluids and constructed a formula which included those factors.

$$Q = K \frac{H D^4}{L} \quad \text{or} \quad K = \frac{Q L}{H D_4}$$

where Q is the outflow amount, H the pressure in mm. of Hg., D and L the diameter and length of the capillary and K a constant varying with the fluid and the temperature.

The physiological aspect of Poiseuille's work seems to have been forgotten for many years. In 1871 Matthews Duncan and Gamgee, studying the mechanical theory of dysmenorrhoea, did a few experiments on the viscosity of blood and drew attention to the findings of Poiseuille.

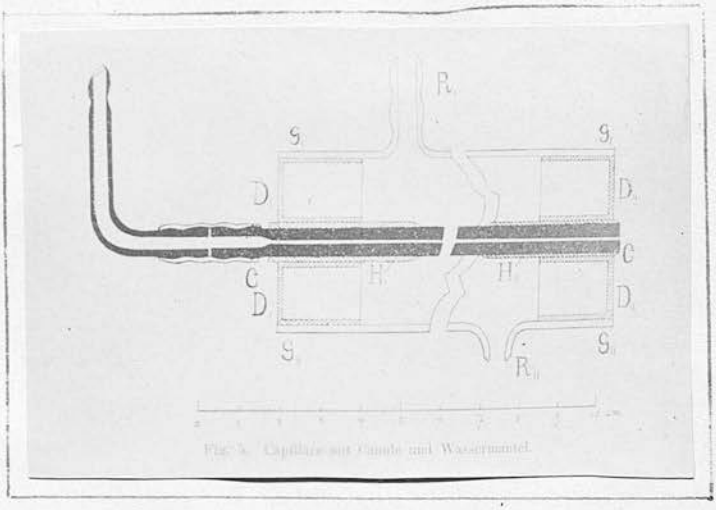
Haro/

Haro (1873) working with a viscosimeter of hour glass design actuated by gravity, confirmed that increased temperature lowered the viscosity of defibrinated blood *in vitro*. He also noted that the addition of CO_2 increased the viscosity and suggested that the slow pulse of asphyxia may be due to this. In 1876 he reported that chloroform, ether and bile salts all raised the viscosity *in vitro*.

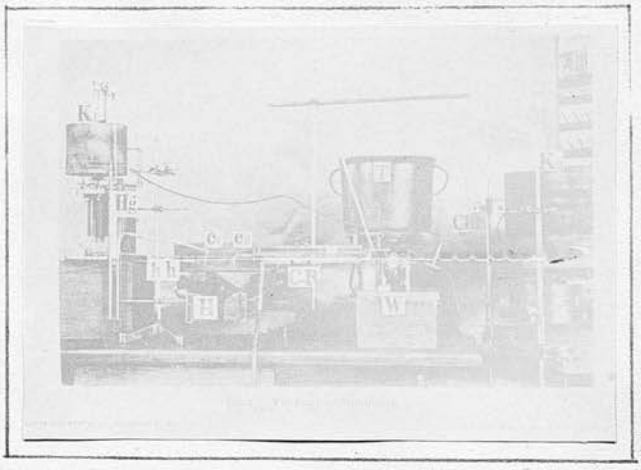
Ewald (1877) found considerable differences in blood viscosity in his patients but could find no definite relation between viscosity and any disease process.

Graham Brown (1894) using an ingenious apparatus fitted with an electric time recorder, investigated the influence of temperature on blood flow *in vitro* and concluded that if the findings were transferable to the living organism, a febrile temperature would be a boon, since the increased rate of flow would considerably lessen the heart work.

Nicholls (1896) in his paper on "Haemodynamics", deals with blood flow in a theoretical manner, basing his remarks on the flow of simple solutions in rigid tubes. He notes that if Poiseuille's law holds there can be no slipping between the vessel wall and the fluid (external friction). The layer of/



HÜRTHLE



HÜRTHLE'S APPARATUS

of fluid which wets the walls, remains motionless, and hence the resistance to steady motion must be altogether due to the viscosity (internal friction) of the liquid.

Lewy (1896) reviewed the existing knowledge of the subject but added nothing to it, except the statement that the Laws of flow were applicable to fluids containing suspended particles. Up till this time all observations had been made on defibrinated or oxalated blood, which might differ very considerably and have no constant relation to the living blood. A new epoch was begun by Hürthle who announced at Toronto in 1897 that by tying a canula into the neck of a dog he could examine the viscosity of the unaltered blood. He shewed that Poiseuille's Law was still valid though the driving pressure varied rhythmically, as in the living body.

A further advance was made by Beck and Hirsh (1901) who introduced an instrument on the Ostwald principle which could be employed in clinical investigations.

From then onwards, the subject received ever increasing attention, each year seeing more and more papers dealing with it. The introduction in 1907 of two simple clinical viscosimeters by Determann and by Hess gave a further stimulus to the investigations, and allowed of the discovery of many important facts.

A complete review of the literature from 1900 to date has been made, but is too bulky to include here.

PHYSICAL CONSIDERATIONS.

A fluid which wets the walls of a tube flows in a series of concentric cylinders, the outer zone remaining stationary and attached to the walls, the axial stream moving most rapidly. From the centre to the periphery, each successive layer moves more and more slowly as if held back by the layer outside it. A simple demonstration of this is seen when washing out a pipette that has been used for measuring blood. When the blood is run out, a thin film remains behind attached to the walls. Suck up more saline and the blood can be drawn to the top of the pipette above a column of clear fluid. Now let the pipette slowly empty itself and the red colour will be seen spreading down the centre of the tube while the peripheral zone remains clear.

Dunstan and Thole (1914) believe that the viscosity of a liquid is at least a dual phenomenon, a mechanical friction of molecule against molecule, depending on relative molecular surface and volume, and secondly a resistance to deformation due to the mutual attraction of the molecules.

The conditions which govern the flow of homogeneous fluids in narrow tubes are expressed by the formula of Poiseuille $M = \frac{\pi R^4 P T}{8 L V}$ where M = quantity/

quantity of blood, R radius of the capillary, L its length, T time in seconds and V a constant varying with the fluid (i.e. its viscosity) and the temperature. Expressed in words the law states that quantity of flow varies with the sectional area of the tube, the pressure and the time and inversely as the length of the tube and the factor V.

$$V \text{ then } = \frac{\pi R^4 \ P \ T}{8 \ L \ M.}$$

Now if one tube be employed in examining two different fluids at the same temperature, all the factors can be eliminated except T (time) so that the ratio $V : V_1 = T : T_1$. The viscosity of blood is usually compared with that of water which for simplicity is given the value 1.

Hence $V = \frac{T}{T_1}$ i.e. the flow time of a sample of blood, divided by the flow time of water, in the same instrument, under the same conditions, gives the viscosity of the blood relative to the viscosity of distilled water. (This "Relative Viscosity" must not be confused with the "absolute viscosity", expressed in C.G.S. units, which was employed by the older workers and is still in use amongst pure scientists.)

In passing, it should be noticed that increasing temperature may affect different fluids to a different extent. This is the case with blood and water.

For/

For normal ranges of blood viscosity, the readings are close enough for practical purposes, but the divergence becomes more and more marked as the thickness of the blood increases and the estimations tend to be too high.

Poisseuille's Law though introduced for simple fluids, has been shewn by Ewald and by Lewy to govern the changes in suspensions such as blood. This has been accepted by most workers and has also been confirmed by physicists working with inorganic fluids. Rothmann (1913), however, doubts the validity and believes that the viscosity depends on the relation of the size of the R.B.C. to the capillary diameter.

Poiseuille's Law is only applicable to fluids which wet the walls of a tube. To test whether the blood wet the arterial walls, Hirsh and Beck (1905), cut open the aorta in a newly killed animal and found a concave meniscus formed by the blood. This was confirmed by Heubner (1905).

Hürthle shewed that Poisseuille's law was still operative though the pressure be varying as in the body.

Much discussion has ranged round the question of the correct pressure to be employed in examinations of viscosity. Müntzer and Block contend that at least 20 m.m. Hg. should be employed, as lower pressures give/

give bad results. Others, complain that too high pressures introduce complications and invalidate the findings. A steady flow such as is required by Poiseuille's Law, is only got where the pressure lies within certain limits, above this point - the "critical speed" of Reynolds - the flow becomes turbulent, some of the potential energy being expended in forming eddies within the liquid. Flow in the living capillaries and arterioles must be slow and under low pressure, so it would seem that similar conditions in the viscosimeter would give the best results.

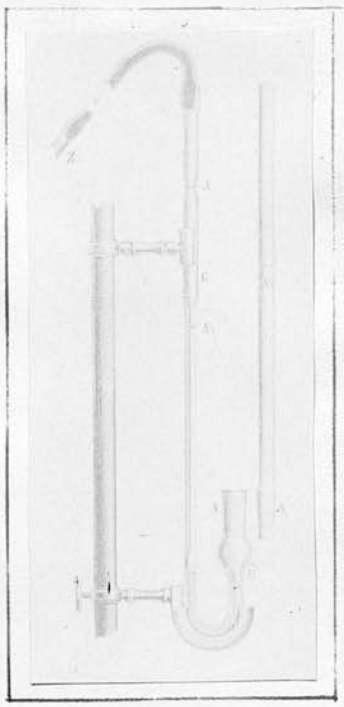
There has been some doubt shewn as to whether the findings in vitro can be transferred to the living body (Rothmann 1913), but most authorities believe that the viscosimeter gives a fairly accurate picture of the internal friction of the blood as exerted in the vessels.

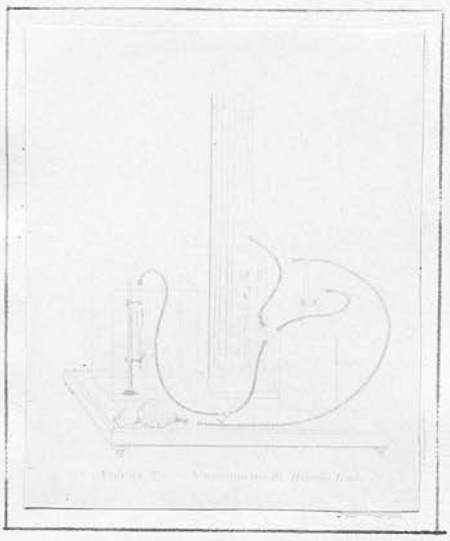
The blood is by no means a simple or homogeneous fluid, but consists of many elements, delicately balanced and apt to be disturbed by minute factors. Regarded as a mixture of corpuscles and plasma, it is a coarse suspension, in which the suspended elements are extremely susceptible to slight alterations in reaction or composition of the plasma.

Since/

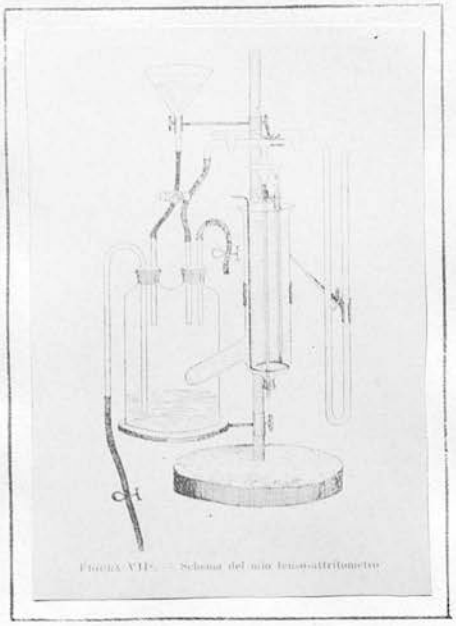
Since the plasma is a watery fluid and wets tubes, it must also wet the surface of the corpuscles and form a thin immovable envelope round them.

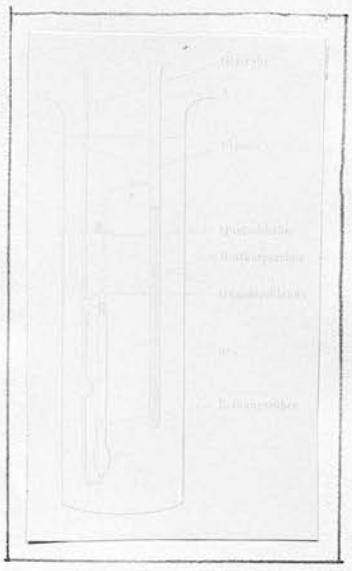
The plasma, too, is a complex liquid, composed of many colloidal and crystalloidal substances which contribute directly to the viscosity and also indirectly, by their interplay on each other and on the corpuscles. Physically the plasma would fall into the class of the "emulsoids".





HIRSCH and BECK





Fillippi

HEUBNER

The choice of a Viscosimeter.

A large number of instruments have been suggested for use at the bedside but they nearly all fall into one of three classes. A great landmark in the Scientific investigation of Viscosity was the introduction in 1894 of an elaborate instrument by Thorpe and Rodger and one of a somewhat different type by Ostwald. These machines require a large quantity of fluid and are unsuitable for clinical use.

Hirsh and Beck (1901) suggested a modified "Ostwald" which only required a small amount of blood. The instrument is a U-shaped capillary tube with two bulbs blown on it, one on either limb at different levels. A quantity of blood is put into it and is sucked up into the higher bulb. It is then allowed to flow through the U part of the tube to the lower bulb under pressure of 452 m.m. of benzol. (= 29 m.m. Hg.); the time taken to pass two marks being noted and compared with the flow time of pure aniline, which, they contend has a specific gravity approximating that of the blood.

Somewhat similar modifications of the Ostwald type have been described by Mayer (1901), Denning and Watson (1906), Fillippi (1909) Luziani (1910), and/

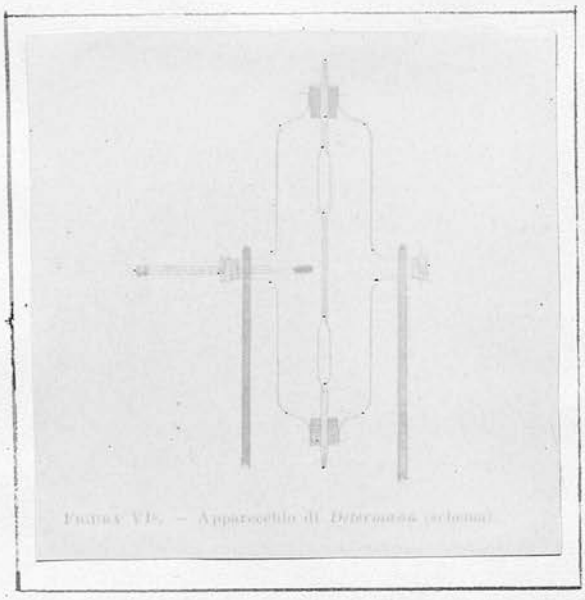
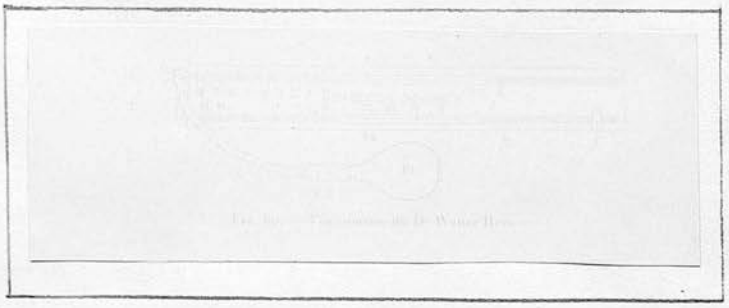


FIGURA VII. — Apparecchio di *Determann* (schema).

DETERMANN



HESS

and Trevan (1918). In some of these the blood was allowed to flow under the pressure of its own weight.

A much more practical clinical instrument was described in 1907 by Determann. This consists of a straight capillary tube with a small bulb near each end, and is enclosed in a glass water jacket which is pivotted at its middle, so that it can be turned with either bulb uppermost. Blood is drawn in up to a definite mark and the time required for the blood to sink from one point to another is noted. The hour glass arrangement allows repeated observations to be easily made. Haro in 1877 had employed a somewhat similar device.

All these instruments allow for the maintenance of a constant temperature during the examination, by the employment of a water bath or a water mantle.

Hess thought that if the examination were made at room temperature, without the use of a regulator, the error involved would not exceed 4%, which is negligible when compared with errors due to the personal equation. His viscosimeter, described in 1907, differs from all the foregoing.
Two graduated capillary tubes mounted horizontally on a board, are connected with a suction bulb in such a way that pressures are equally distributed between them. Into a small reservoir at the end of one tube is put some distilled water and a portion of the other/

other tube is detachable, so that it can be readily filled with the blood sample. Suction is applied for a short time and the fluids are drawn up to different levels in inverse proportion to their thickness. A comparison of the readings at once gives the relative viscosity. This instrument is very simple and easy to manipulate, but has several disadvantages, especially a lack of means to control the temperature and the pressure employed.

Münzer and Block (1912) after elaborate experiments with different instruments and tubes under varying pressures, introduced a modification of Hess' instrument having a water jacket and a vacuum bottle which could be exhausted to any required degree. These refinements make it rather cumbersome for general use.

Robert-Tissot (1907) relying on an entirely different principle, produced an intricate piece of mechanism which he claimed to be "the simplest form of viscosimeter". A plunger dipping into a test fluid is set in motion and the viscosity is calculated from the rate the oscillations are damped down. That the results obtained with such an instrument tally closely with those got by other methods, speaks well for the reliability of viscosimetry.

Simplification has been carried too far in some instruments/

instruments at the expense of accuracy. This is the case in MacCaskey's (1911) and in the clinical apparatus of Denning and Watson (1906) (No fault can be found with the very elaborate apparatus the latter authors employed in their laboratory experiments.)

Of the instruments mentioned, those of Determann and of Hess have had the greatest vogue. Comparison of the results obtained with these viscosimeters shewed that the figures with the Hess machine were lower than those in the Determann's and much controversy has raged between the opposing partisans over this question. Determann, who employs the weight of the blood column as driving force (= about 7.35 m.m. Hg.) states that the Hess instrument allows too high and varying pressures, which give false results by introducing "turbulent flow". The supporters of Hess, on the other hand, say that the correct pressure should be between 50 and 60 m.m. of mercury, and that the weight of the blood is not sufficient. They also suggest that the vertical arrangement in Determann's machine and the slow rate of flow will allow of sedimentation of the corpuscles.

On physical grounds the viscosimeter of Determann, appears to be the soundest and most reliable.

I/

I have made use of three different types. Denning and Watson's clinical apparatus was soon set aside as being utterly unreliable and none of the results obtained with it, have been included. All the clinical observations were made with Determann's model, and for the laboratory investigations where it was desirable to employ large quantities of blood, a modified "Ostwald" was used.

The use of Hirudin as an Anticoagulant.

Before the introduction of Leech extract, observations were made on oxalated or defibrinated blood, which, of course, differed considerably from normal blood. Some authors, e.g. Hess, trust to the speed of their manipulations and add no anticoagulant to the blood. They can only make single observations on each sample and even then the results will frequently be vitiated by the early onset of coagulation. Krone (1910) doubts the value of all results obtained without the use of Hirudin.

Hirudin is now almost universally employed in examinations of the blood viscosity. By its use, clotting can be indefinitely delayed, and the blood can be handled as an ordinary fluid and examined as often as is desirable. Most authorities state that it does not physically alter the blood in any way. A few, however, believe that it facilitates sedimentation of the corpuscles. It is difficult to see how this can be so (apart from its action as an anticoagulant) since the minute amount of hirudin employed, does not alter the composition of the plasma.

The question was tested by making some rapid examinations of blood without the addition of hirudin and comparing the results with hirudinised blood taken at the same time. More extended observations were made on the blood from a case of haemophilia with the following satisfactory results.-

	V.	R.B.C.	Hb.	W.B.C.		
Male aged 11	2.75	3510000	46	17000	with hirudin	(Sept. 7th)
	2.75	-	-	-	without hirudin	"
	2.75	2610000	53	11200	with hirudin	(Sept. 29th)
	2.75	-	-	-	without hirudin	

The boy got an injury to his scalp on 18th August, the wound oozed for one day, then dried up and remained well till September 2nd when it began to bleed very badly. Oozing continued for a long time in spite of very active treatment.

Points to be observed in taking samples of blood and in working the Viscosimeter.

It is well known that samples of blood taken from different parts of the body may differ greatly in composition and in gaseous content. Hess recommends congesting a finger by dipping it in warm water and then carefully drying it before taking the sample. Congestion of a finger by a constricting band, even for a few seconds may concentrate the plasma or raise the amount of carbon dioxide. Blood from a vein is dark in colour and always has a higher viscosity than arterial or capillary blood.

All these methods are open to objection and only blood from the lobe of the ear should be employed. Even here precautions are necessary. The composition of the blood sample depends on the character of the puncture and if uniform results are to be obtained, a very free flow is required. Such free flow means that the blood is coming from larger vessels and is unmixed with lymph (or only slightly so). A slower flow will allow admixture with tissue juices and changes may occur in the blood before it can be examined.

To ensure a successful flow a practice was made of first congesting the ear by friction and then making two large punctures in it.

The/

The following figures illustrate these points.-
(182) A sample of blood which oozed slowly from a single small puncture gave a reading of 5.50. Later two deep punctures were made so that the blood came rapidly and formed a hanging drop from which the instrument was filled. The reading was now 4.25.

These findings were confirmed in other cases.

In working the viscosimeter it is well to discard the first few readings while the walls of the instrument are being wetted, as these tend to be too high. The figures soon reach a constant level, e.g.

(No.4)	No. of Reading.	Viscosity	R.B.C.	Hb.	W.B.C.
	(1)	7.87	6310000	110	6200
	(2)	6.92			
	(3)	6.75			
	(4)	6.75			
	(5)	6.75	and so on.		

Effect of Sedimentation.

If it is necessary to leave the blood in the instrument for some time before examining it, the corpuscles tend to settle by gravity to the lower part of the fluid and leave the upper layers cell free. This unequal distribution profoundly alters the values observed, e.g.

When/

When first examined a blood gave V = 4.55; R.B.C. 4870000; Hb. 88.
After being allowed to settle, successive readings were.-

(1)	3.87
(3)	4.00
(5)	4.25
(7)	4.30
(10)	4.37
(12)	4.45
(16)	4.50
(20)	4.55 the original constant.

Where the blood is thicker an opposite result may appear.

A case of jaundice gave V = 6.52, R.B.C. 5150000, Hb. 84. After standing some time the corpuscles settled into visible clumps and the reading was V = 7.50 ; then after much running the blood appeared to be thoroughly mixed and the figure was now 6.87. Hence a perfect mixing of the blood elements is essential for a correct estimation of viscosity.

All Air Bubbles in the instrument must be carefully avoided. A small bubble in the bulb is of little account, but when it slips into the narrow part of the tube it at once acts as a brake. Two tiny/

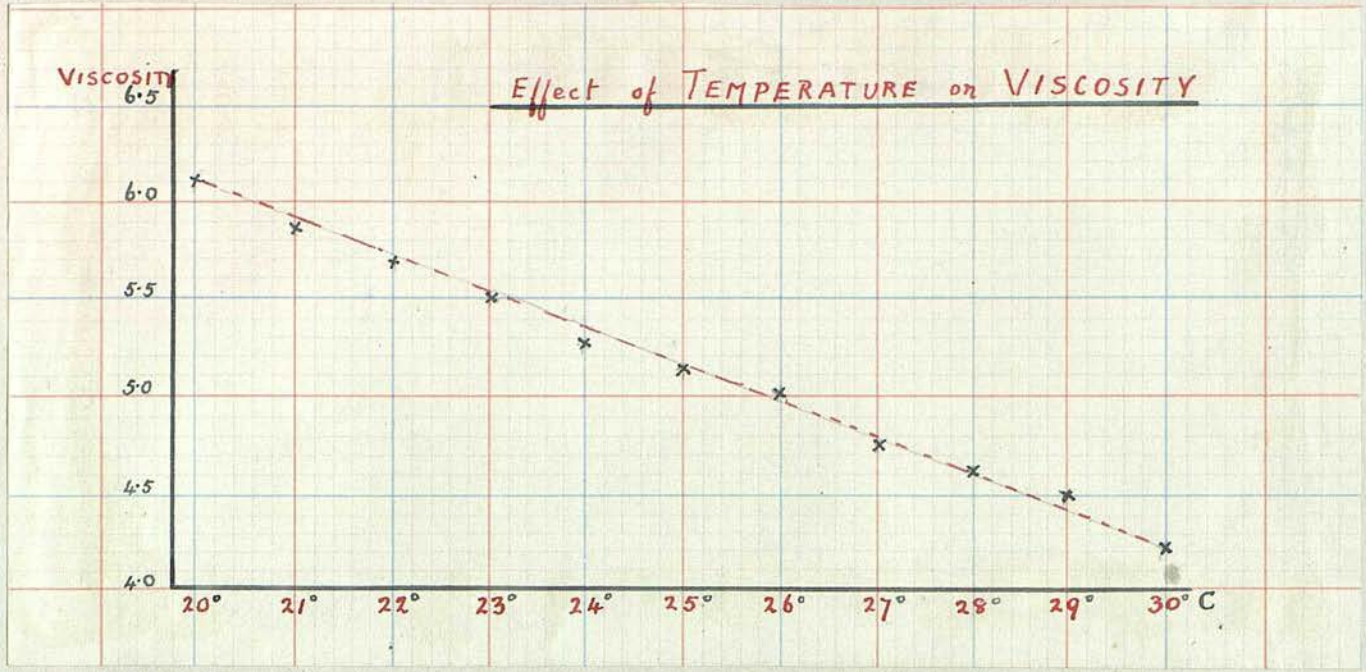
tiny air bubbles lengthened the flow time in one case from 23 to 30 and three bubbles were sufficient to prevent all flow.

A very slight error in the quantity of blood in the instrument causes considerable difference in the readings, but the zero mark is on a narrow part of the tube and with reasonable care such an error is impossible. Excess of flow reduces the flow time, shortage lengthens it.

The temperature of the water in the mantle must be kept at the standard temperature (20° C.) in order that readings may be comparable. Specially constructed tables shewing the necessary correction can be employed where it is impossible to maintain a uniform temperature.

All observers have noted the influence of temperature on the viscosity of fluids. With rise of temperature the fall in viscosity is rapid and uniform and can be graphically represented by a straight line. When higher temperatures are reached, heat coagulation of proteins upsets this regular change, but this is outside the range of temperatures likely to be observed.

Numerous experiments were conducted to test the effect of increased heat on the viscosity. The following is a typical result - the figures being the averages/


Effect of TEMPERATURE on VISCOSITY
VISCOSITY
6·5
6·0
5·5
5·0
4·5
4·0
20°
21°
22°
23°
24°
25°
26°
27°
28°
29°
30° C

averages of 130 readings lasting over 2 hours. The Blood shewed

V = 6.10 R.B.C. 5300000 Hb. 100.

Temperature	20°C.	21	22	23	24	25	26	27	28	29	30
Viscosity	6.10	5.87	5.68	5.50	5.25	5.12	5.00	4.75	4.62	4.50	4.20

The difficulty of keeping the temperature of the water jacket at 37° C. is obvious and all results quoted are from readings at 20° C.

In using Determann's instrument it is essential to see that the apparatus is absolutely vertical since any departure from this position lengthens the flow time.

Normal Variations in Viscosity Readings.

Before considering the alterations in viscosity found in disease, it was necessary to find out what range of figures occurred under normal conditions. To ascertain this, upwards of 80 normal cases were examined. These gave an average viscosity of 5.21 for males, the figure for females being a little lower.

Welsh (1911) using a similar instrument found 5.42 for males and 5.12 for females; while Determann (1908) gives 4.798 and 4.516 respectively; and Jorns 5.37 and 5.08.

Workers with the Hess instrument found somewhat lower figures. Hess gives the normal range for males 4.3 - 5.3 and for females 3.9 - 4.0, Bachman 4.7 - 4.3, Austrian 4.55 and 4.51, Matsuo 4.428 and 4.017, Martinet 3.8 - 4.5 and Trunpp 4.25.

Readings obtained with the Hirsch and Beck apparatus more resemble those got with Determann's, e.g. Hirsh and Beck gave 5.1, Kottmann 5.11, Rotky 5.12 and Bence 5.4.

It is of interest to note that instruments depending on quite different principles give closely similar results. Robert-Tissot found males 4.79 and females 4.51, and McCaskey 4.5 - 5.5.

In the older papers where defibrinated blood was employed the readings are of course somewhat lower.

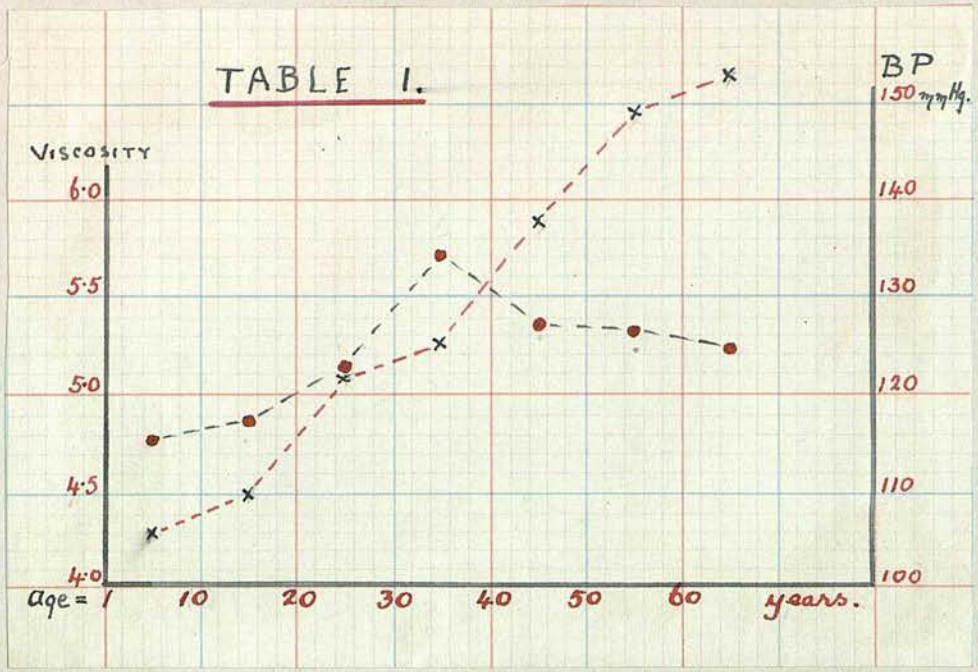


TABLE I.
BP
150 mm Hg.
140
130
120
110
100
VISCOSITY
6·0
5·5
5·0
4·5
4·0
Age = 1
10
20
30
40
50
60
years.

Variations in Viscosity due to Age.

TABLE I.

Age	Viscosity	R.B.C.	Hb.	B.P.	Hb/V	BP/V	C.I.
Under 10	4.78	4650000	86	106	18	22	.92
10 - 19	4.88	4620000	88	110	18	22.5	.95
20 - 29	5.12	4660000	90	122	17.5	23.8	.96
30 - 39	5.73	4980000	94	125	16.4	21.8	.94
40 - 49	5.39	4810000	92	138	17.05	25.6	.96
50 - 59	5.33	4690000	88	149	16.5	27.9	.94
60 upwards	5.24	4680000	89	153	16.9	29.1	.95

From the foregoing table it will be seen that the viscosity rises with increasing years, till it reaches a maximum in the period 30 - 39, and that the No. of R.B.C. and the Hb. attain their highest point at the same time. After 40 years of age these figures steadily fall. On the other hand, the Systolic Blood pressure shews no maximum at middle life but continues to rise steadily as age advances. This rise and fall of blood viscosity is also noticed by Hess (1904).

Age	0-10	10-20	20-35	35-50	50-81
Viscosity	3.89	4.43	4.70	4.91	4.62

The age periods are somewhat longer in this case and do not give such a good idea of the true curve.

Since the viscosity readings vary so greatly at different times of life, it will be necessary to compare the figure given by each patient with the normal for his age. No stress seems to have been laid on this point by previous workers, who content themselves with employing one standard only.

Blood Viscosity at different times of day.

Empyema Convalescent, aged 8.

Date.	Hour.	Viscosity.	R.B.C.	Hb.	Sp. Pr.	B.P.	Last Meal.
19 Sept.	10.15 a.m.	5.00	4740000	93	1058	103	8.30 a.m.
"	12	5.10	4690000	93	1058	104	"
"	2.10 p.m.	5.30	-	-	-	-	12.30 p.m.
"	4.5 "	5.10	-	-	1057	102	"
"	7.30	5.00	-	-	-	-	6 p.m.
28 Sept.	10.45 a.m.	5.15	4800000	93	-	104	8.30 a.m.

Like other body constants, Temperature, etc., the viscosity of the blood varies within narrow limits throughout the day. In the above example the difference between the lowest and highest figures is but 6%. Blunschy (1908) found a daily variation of 11.8%, the highest reading being got in the morning, followed by a fall as the mid-day meal approached when the viscosity rose again, to fall once more as the afternoon advanced, the lowest readings being got between 2 and 6 p.m. Martinet (1912) believes that the viscosity does not vary more than .2% during the day. Most authorities note that the number of red corpuscles and the water content of the blood vary throughout the day, these changes being attributed to exercise and to digestion. Starling (1909, p.75,) states that the composition of the blood is altered by meals, a Blood shewing 5000000 R.B.C. with a Sp. Gr. of 1061 rose to 5400000 and 1065 one and a half hours after a meal, and fell to normal two hours later. Ewing (Clin. Path. of Blood 1904, p.92) states that the No. of R.B.C. gradually falls during the day and rises at night. For an hour or so after meals the R.B.C. are temporarily reduced. Schäfer shews that these variations may amount to 4 - 5% of the normal number of cells. Robert-Tissot (1907) and Burton-Opitz (1902) note that viscosity is higher in hunger than during digestion.

Viscosity readings from day to day.

McGill, aged 16.

Date	Time	Viscosity	R.B.C.	Hb.	B.P.	Last Meal	Room Temperature.
25 Aug.	5.5 p.m.	5.02	4570000	88	115	5 p.m.	18° C.
28 Aug.	10.20 a.m.	4.95	4540000	88	106	8.30 a.m.	17° C.
31 Aug.	11 a.m.	4.95	4780000	88	107	"	16
2 Sept.	11.25 a.m.	4.82	4730000	88	105	"	17
6 Sept.	10.35 a.m.	5.02	-	-	108	"	16.2 Windy.
14 Sept.	10.50 a.m.	4.93	4720000	89	108	"	14.2

A large number of cases were repeatedly examined over considerable periods. Changes in viscosity from day to day were found to be very slight - in the above example amounting to only 4%.

Several observers note that the variations under normal conditions are very small, while in disease very profound changes may be present.

White (1911) working with dogfish, found the highest daily variation to be only 3%.

Hürthle (1900) found the blood viscosity in dogs to be higher in summer than in winter.

From the above observations it will be evident that the blood must be examined under as uniform conditions as possible, especially as regards relation to meat times, time of day and exercise. Also, since the variations due to age and sex are even more considerable, it will be necessary to keep them in mind when comparing a pathological finding with the normal.

Analysis of factors influencing Blood Viscosity.

Before proceeding to examine the results obtained in diseased conditions, it is desirable that we should analyse as far as possible the factors which contribute to the Blood Viscosity.

Nearly all observers agree that the Viscosity does not depend entirely on any one constituent of the Blood, but a review of the literature shews a considerable difference of opinion as to which element is the most important. Most authors allude to the importance of the formed elements.

R.B.C. and Blood Viscosity.

Ewart (1904), Burton Opitz (1907), Bachmann (1909), Welsh (1911), Josué and Parturier (1916) consider the Red Blood Corpuscles the principal factor in the production of the viscosity. Amerling (1911) suggests that the correspondence is so close, that the viscosity might be examined in order to get an idea of the number of R.B.C. present.

Most other authors, while recognising some parallelism between the Viscosity and the R.B.C., consider the corpuscles of secondary importance. Rotky (1907) and Kottmann (1907) deny that there is any regular relationship and hence the corpuscles have/

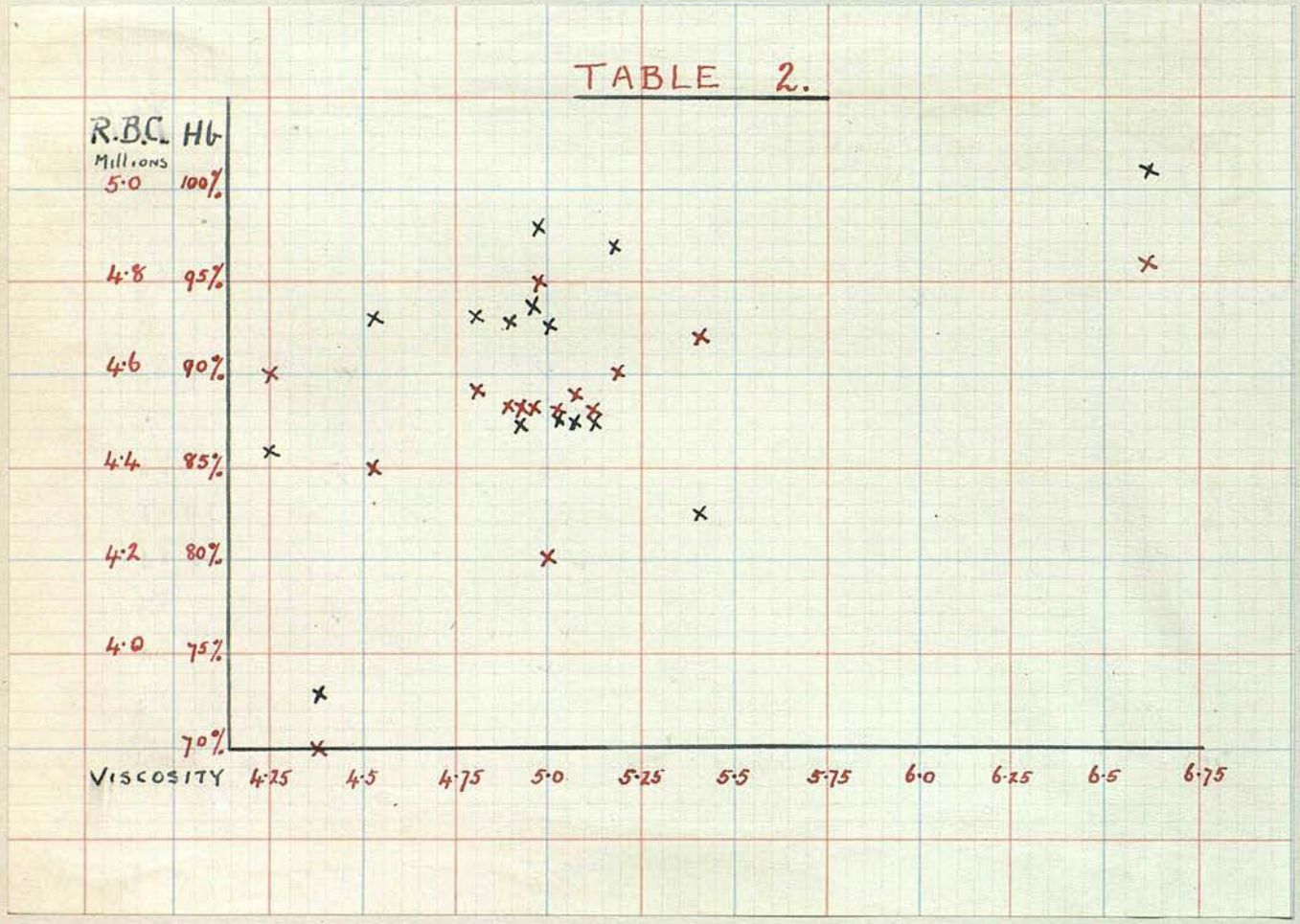
have no marked effect on the total viscosity.

Weill and Gardère (1912) believe that all variations of over 10% from the normal must be attributed to the R.B.C.

This divergence of opinion is to be attributed largely to the class of data the author has at his command. If he has confined himself to making clinical observations, the relationship is not striking, but as soon as in vitro experiments are made the part played by the corpuscles is too obvious to escape notice.

TABLE 2./

TABLE 2.



Black cross = ht. of die
= 176 %

TABLE 2.

V to No. of R.B.C.

(Clinical observations on Normal Cases.)

Case	Age	Viscosity	No. of R.B.C.	Hb.
41	6	4.25	4450000	90
76	52	4.38	3930000	70
42	17	4.55	4740000	85
216	16	4.87	4730000	89
248	16	4.92	4720000	88
193	16	4.95	4540000	88
206	16	4.95	4780000	88
49	-	5.00	4960000	95
14	8	5.00	4730000	80
189	16	5.02	4570000	88
222	12	5.05	4520000	89
192	16	5.12	4540000	88
16	13	5.18	4870000	90
12	44	5.38	4330000	92
11	36	6.62	5030000	96

TABLE 3.

No. of R.B.C. to V.

Case	Age	No. of R.B.C.	Viscosity.	Hb.
278	26	4510000	5.57	87
232	21	4670000	5.25	91
195	69	4710000	5.12	92
47	32	4720000	5.30	90
170	62	4770000	4.70	95
183	34	4980000	5.35	94
127	62	5060000	4.75	95
66	23	5190000	5.25	95
90	37	5460000	6.25	98

A comparison of the foregoing tables shews that the movements of the Viscosity and the Number of R.B.C. are by no means uniform or close, though it is true that the high figures in each case occur at the same end of the tables. Both Trumpp and Scheitlin point out that high and low values of viscosity and R.B.C. correspond while the middle figures do not. This is further exemplified by the following details taken at random from the tables of disease conditions.

Case	Age	Viscosity	R.B.C.	Hb.	Diagnosis.
121	50	2.25	1640000	34	Pernicious Anaemia.
306	26	2.75	1810000	46	Ditto.
389	20	3.98	3150000	72	Ditto.
86	22	6.40	5570000	106	Mitral Stenosis.
321	34	8.50	5440000	103	Cardiac Failure.
424	21	11	7520000	112	Severe Mitral Stenosis.

The older writers, recalling the tendency of the red blood corpuscles to run together and form rouleaux, speak of the corpuscles themselves being viscous and believe that they increase the viscosity by rubbing against each other. This view is no longer tenable, since it has been proved that solid particles in a fluid exert a passive influence and only become important when they approach so close together that their attraction spheres are practically continuous.

Volume of R.B.C. and Blood Viscosity.

Josué and Parturier (1916) claim that a much closer parallelism exists between the volume of the R.B.C. and Viscosity than between the Viscosity and the Number of the Red Cells.

Kottmann (1907) also points out the importance of the corpuscular volume and says that both the number and the volume of the R.B.C. must be estimated to give a complete idea of the rubbing surface. A few other writers who have worked at the question recognise the importance of the corpuscle volume, while Trumpp (1911) and Blunschy (1908) could find no exact ratio.

A number of cases were specially examined to investigate this question and the results will be found tabulated below (Table 4.) It will be noticed again that increase in R.B.C. Volume is closely followed by rise in the blood viscosity. Some discrepancies occur, but reference to the columns shewing Hb. and No. of R.B.C. will usually afford an explanation.

Larrabee's (1911) Volume index $\frac{\text{Percentage Volume}}{\text{(Percentage No. RBC)}}$ has also been worked out and tabulated. It varies most irregularly and in no way corresponds to the viscosity.

Similarly the colour index bears no obvious relation to the viscosity figures.

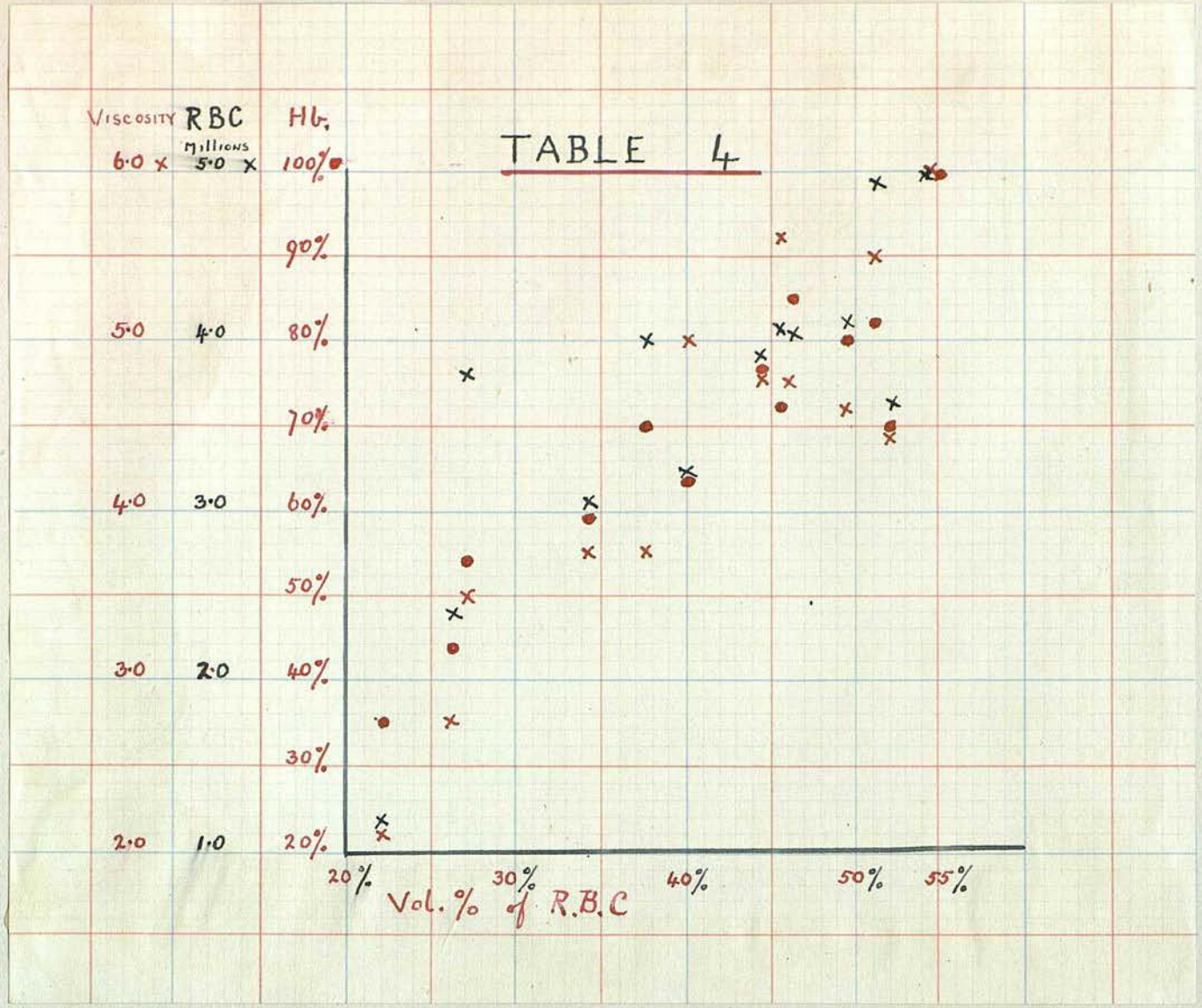


TABLE 4
Viscosity
RBC
Millions
Hb.
6·0
5·0
4·0
3·0
2·0
5·0
4·0
3·0
2·0
1·0
100%
90%
80%
70%
60%
50%
40%
30%
20%
20%
30%
40%
50%
55%
Vol. % of R.B.C

TABLE 4. Volume of R.B.C.

Case	Sex	Age	Vol.%	Viscosity	R.B.C.	Hb.	Vol.Ind.	Col.Ind.	Remarks.
499	F.	23	22.2	2.1	1060000	35	1.06	1.65	Anaemia of Pregnancy.
507	F.	53	26.7	2.75	2400000	44	1.11	.02	Secondary Anaemia.
506	M.	65	27.1	3.5	3790000	54	.71	.71	Acute Nephritis.
494	M.	7	34.6	3.73	3050000	59	1.13	.96	Acute Nephritis.
501	M.	43	37.64	3.75	4040000	70	.93	.86	Pleurisy $\overline{c}$ Effusion.
503	F.	20	40.06	5.02	3250000	63	1.23	.91	Acute Pericarditis.
497	M.	48	45.00	4.76	3920000	76	1.12	.97	Rheumatoid Arthritis.
513	F.	20	45.2	5.40	3850000	70	1.4	.91	Exophthalmic Goitre.
511	M.	14	45.3	5.60	4080000	72	1.11	.88	Acute Meningitis.
510	M.	17	45.7	4.03	4300000	65	1.06	.76	Lymphatic Leukaemia.
491	M.	21	47.7	4.75	4040000	85	1.18	1.05	Diabetes Mellitus.
500	M.	21	49.6	4.57	4120000	80	1.2	.97	Mitral Stenosis.
505	M.	64	51.25	5.50	4950000	82	1.03	.80	Arterio-Sclerosis
492	F.	48	52.5	4.45	3650000	70	1.42	.91	Carcinoma of Sigmoid.
508	M.	23	54.65	6.00	5010000	100	1.09	.99	Mit. Sten. $\overline{c}$ Cyanosis.

Haemoglobin percentage and Blood Viscosity.

An examination of the tables given above will shew a very close parallelism between the Hb. percentage and the viscosity, but once more the relationship is not exact.

Bachmann in 1908, claimed that he had found a constant in the quotient $\frac{Hb}{V}$. The normal he said should be about 20 ($\frac{Hb}{V} \frac{90\%}{4.5} = 20$) with a range of 17 - 21.

Matsuo (1912) got somewhat higher figures.

Hess, Trumpp, Austrian and Determann point out that the $\frac{Hb}{V}$ quotient is low in anaemias and in acute infections - Typhoid, Pneumonia, Measles, Scarlet and Diphtheria - but these observations do not help in diagnosis and prognosis.

In Normal cases I have found the quotient to lie between 16.4 and 18, the lower figures being due to the higher reading which is obtained with Determann's instrument. (Bachmann and most of the other observers employed the Hess Machine.)

Where discrepancies exist between the viscosity and corpuscular readings, it may be found that the haemoglobin is unusually low or high, and an unexpected R.B.C. count may explain a divergence between/

between the figures for haemoglobin and viscosity. It would therefore appear that a factor including both R.B.C. and Hb. might show a more constant relationship. Figures corresponding to the formula $\frac{\text{R.B.C.\%} + \text{Hb.\%}}{2}$ have been worked out for the above tables and these do give a slightly better correspondence. The product of these figures (R.B.C.% X Hb.%) has also been tried with no greater success. Discrepancies are still so marked that it must be concluded that other factors are concerned in the question.

Specific Gravity* of the Blood and Viscosity.

Although the Specific Gravity of the blood depends closely on the amount of Hb. present in it, the relation between Viscosity and Specific Gravity is by no means as near as that between Viscosity and haemoglobin. A few authors find some correspondence, but most do not, while Adam (1907) and McCaskey (1908) point out that the two factors may vary in inverse direction, a low Viscosity being associated with a high Specific Gravity and conversely.

TABLE 5./

* The Sp. gr. was estimated by Hammerschlag's method.

TABLE 5.

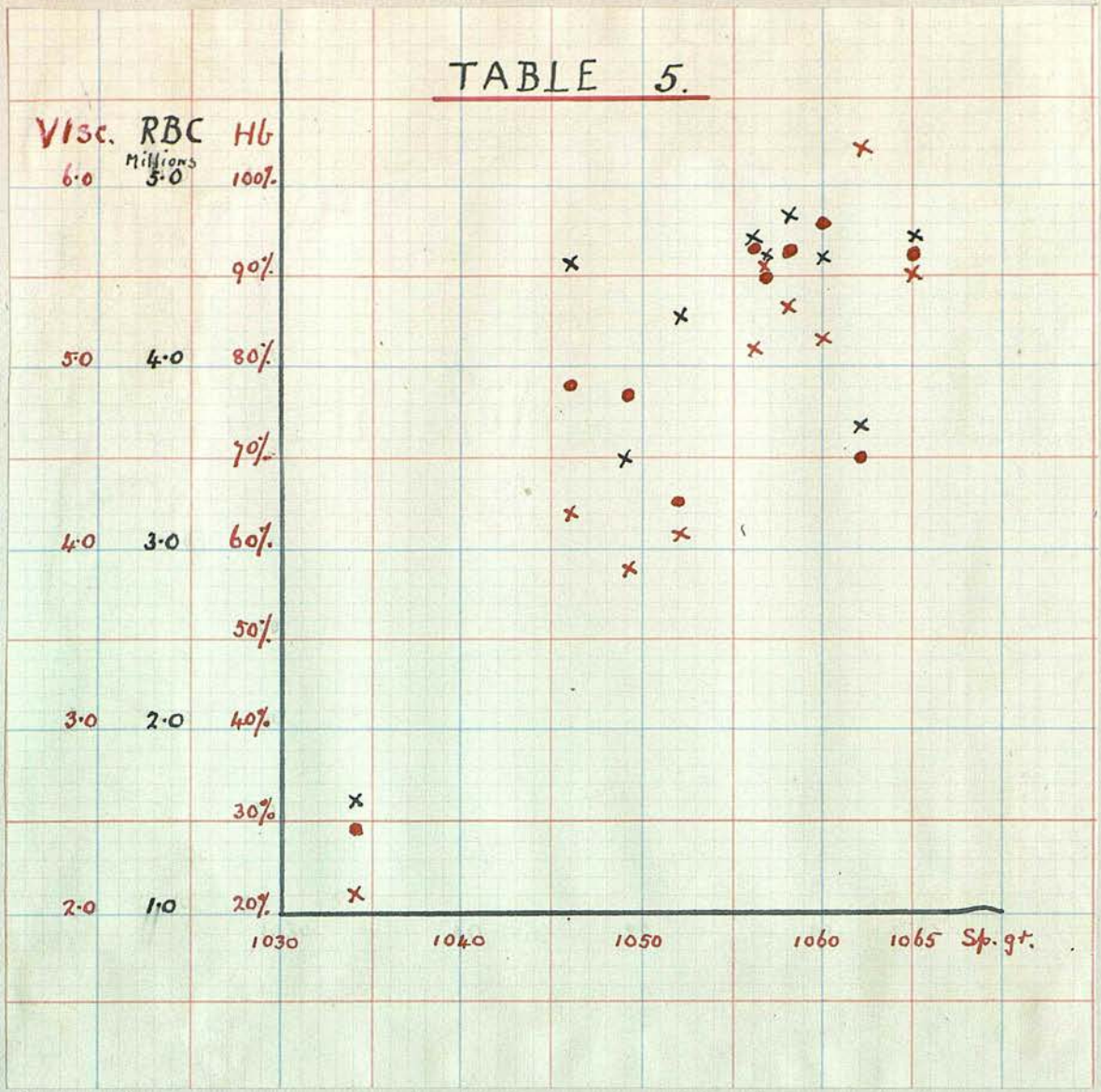

Visc.
RBC
Millions
Hb
6·0
5·0
100%
90%
5·0
4·0
80%
70%
4·0
3·0
60%
50%
3·0
2·0
40%
30%
2·0
1·0
20%
1030
1040
1050
1060
1065
Sp. gr.

TABLE 5. Specific Gravity.

Case	Age	Viscosity	Sp. gr.	R.B.C.	Hb.	Remarks.
458	36	2.07	1034	1580000	29	Pernicious Anaemia.
245	19	4.20	1046	4560000	78	Chlorosis.
251	44	3.88	1049	3490000	77	Exophthalmic Goitre.
487	9	4.07	1052	4340000	65	Latent Typhoid.
264	8	5.10	1057	4690000	93	Convalescent.
250	46	5.58	1057	4610000	90	Subacute Nephritis.
259	8	5.00	1058	4740000	93	Convalescent.
261	8	5.10	1058	4690000	93	Convalescent.
258	32	5.50	1058	4870000	96	Phlebitis. C.H.
260	46	5.65	1058	5030000	90	Subacute Nephritis.
269	22	5.15	1060	4590000	96	Convalescent.
488	44	6.25	1062	3650000	70	Pontine Haemorrhage - Dyspnoea.
485	65	7.50	1063	4400000	92	Moribund - Cyanotic, etc.
225	54	5.50	1065	4720000	92	Phthisis.

As the Sp. gr. rises the viscosity readings also tend to mount, but several of the figures seem out of place. Reference to the R.B.C. and Hb. columns may explain some of them, others still elude us. The extra high results - 6.25 and 7.50 - are due to the cyanosis present in these cases.

Blood "Alkalinity" and Viscosity.

In 80 cases parallel observations were made on the blood viscosity and "blood alkalinity" to see if any connection could be observed. The "alkalinity" was measured in most of these cases by the Flocculent Precipitate Reaction of Boycott and Chisholm (1909). In a few Wright's Method was employed and in others that of Landois.

No relationship was to be noted, each level of alkalinity shewing a wide range of viscosity figures. Where the same case was examined on several occasions there seemed to be a tendency for the alkalinity and viscosity to vary inversely, but this was by no means constant.

One of the lowest Alkalinity readings was got in a moribund and very cyanotic case associated with a viscosity of 7.50.

It is highly probable that parallel estimates of the blood viscosity and the H-ion concentration of the blood would reveal interesting results, but I have not yet had an opportunity of making such observations.

Gaseous Content of the Blood.

It is well known that blood from different parts of the circulation may vary considerably in its characters. Many workers have pointed out that venous blood has a higher viscosity than arterial or capillary blood, and attribute this to the amount of carbon dioxide carried. Lauder Brunton in his "Therapeutics of the Circulation" remarks that a poor blood flow during venesection can be immediately improved by giving the patient oxygen inhalation. The high viscosity readings obtained in cases where cyanosis is present are reduced by oxygen administration, and several observers, e.g. Austrian (1911) and Broking (1909) - note that in rebreathing experiments, the blood viscosity rises with the increase of carbon dioxide in the blood. This increase in viscosity is explained by the control which carbon dioxide exerts on the distribution of salts and water between the corpuscles and the plasma. Hamburger (1893) pointed out that carbon dioxide increased the volume of the red blood corpuscles and altered their permeability. von Limbeck (1895) confirmed this and shewed that increase of CO_2 raised the number of R.B.C. per c.m.m., and increased the thickness of the blood, as well as the Nitrogen content and the solids of the plasma, while the volume of the plasma and its NaCl diminished. The R.B.C. increase in volume by taking/

taking up water, chlorides and nitrogen.

On the other hand Rotky (1907) claims that CO_2 also raises the viscosity of the plasma and Adam (1909) who denies that CO_2 has any action on the plasma, shews that the viscosity of laked blood is considerably raised when CO_2 is passed through it. These observations suggest that the changes in the R.B.C. are not the only cause of the altered viscosity.

Experiments on the viscosity of inanimate suspensoids shew that, within limits, the size of the particles matters little, though their total volume per unit of the solution is of consequence.
It is probable, then, that the raised viscosity resulting from increase of CO_2 is to be attributed chiefly to concentration of the plasma and to a direct effect of the gas on the plasma colloids. Almost the only dissentient is Langstroth (1919) who could not demonstrate any relation of the viscosity to the CO_2 or O_2 content of the blood.

Venous Blood. The influence of carbon dioxide on the viscosity can be readily seen when samples of blood are simultaneously examined from the ear and from an arm vein during venesection, e.g.

(A) Cerebral Haemorrhage case.	Blood from ear 5.625, from vein 6.075
(B) Similar case.	" " " 5.5 , " " 5.58

In both cases the blood withdrawn from the vein was obviously much darker in colour than the other.

Local Stasis of the circulation such as can be produced by the application of a rubber bandage on a limb also causes profound increase in the viscosity of the blood in the part. This has frequently been pointed to as additional evidence of the action of CO_2. While part of the increase may be due to this cause, it must be remembered that the blood may be concentrated in the stagnant area by the raised pressure leading to increased passage of fluid from the blood into the tissues. (c.f. Leonard Hill - "Further advances in Physiology" p. 167)

The effect of congesting an arm for one hour with a Martin's bandage is seen in the following experiment.-

Blood from finger taken at once V = 4.575 (R.B.C.vol. = 49.6%)

Taken 1 hr. later V = 7.00 (R.B.C.vol. = 51.65%)

The slight congestion of the finger necessary to obtain a sample of blood makes a little difference in its composition and this should be borne in mind when samples have to be taken from a finger for blood counts.

e.g. Blood from 2 fresh punctures on the ear V=5.3

Blood from similar punctures on congested finger . . . . V=5.4

The influence of carbon dioxide can be readily demonstrated in vitro.- e.g.

Reading when taken	= 7.87
After CO_2 bubbled through	= 8.25
After shaking with air	= 7.30

This experiment was repeated several times with samples of normal blood, oxalated blood and mixtures of washed corpuscles in plasma.

The presence of visible bubbles of gas in the fluid, such as appear after shaking with air or CO_2 greatly increases the viscosity reading.

Corpuscular emulsion, dark from standing.	V = 7
After 2 mins. shaking with air —	
Fluid now bright but shews minute bubbles	V = 7.5
After bubbles have disappeared . .	V = 6.75

Cyanosis and Blood Viscosity.

The hyperviscosing effect of carbon dioxide on the blood can be well demonstrated in cases shewing cyanosis or dyspnoea.

TABLE 6./

TABLE 6.

Case	Sex.	Age	Viscosity	R.B.C.	Hb.	Date.	Remarks.
309	M.	28	5.95	5320000	96	(7 Nov.)	Chr. Emphysema etc. Cyanosis and great oedema.
"	"	"	6.25	5170000	99	(9 Nov.)	Great dyspnoea, Blood very dark. (Died 12th.)
485	M.	24	6.10	5100000	92	(30 May)	Mit. Stenosis, Cyanosis, No oedema.
			6.00	5080000	100	(11 June)	Somewhat inproved.
85	M.	34	6.87	5150000	100	(29 June)	Aneurism, Dyspnoea, Cyanosis.
			6.10	5080000	98	(7 July)	Breathing easier, looks much better
334	M.	25	7.02	4670000	98	-	Chronic Bronchitis, Blood very dark
321	F.	34	8.50	5440000	102	-	Mit. incompetence, Dyspnoea and oedema.
404	F.	40	9.75	5570000	100	-	Bronchopneumonia, Great Cyanosis.
477	M.	28	10.07	5240000	110	-	Cerebral Haemorrhage, Comatose, Died a few hours later.

Similar results were shewn by many other cases which will be readily recognised in the tables of diseases. In the above group, it will be noticed that the readings are high in two of the cases where oedema was also present.

Amongst the series of patients shewing cyanosis were two who also suffered from severe vomiting, the combination raised the viscosity to a very high level, e.g.

Case 101	Sex	Age	Viscosity	R.B.C.	Hb.	Remarks.
6 July	M.	43	5.60	5770000	102	Arterio sclerosis.
31 Aug.	"	"	10.9	6370000	112	Very Cyanotic, vomiting all food. Complains of severe cramps.
4 Sept.		"	6.25	5190000	100	No cyanosis, vomiting nor cramps.

Blood Plasma and Viscosity.

The influence of the fluids of the blood on the total viscosity is well shewn by conditions which withdraw fluids from the circulation, the perspiration of fever and muscular exercise, vomiting, diarrhoea and diuresis, etc.

The changes produced by the hot air bath illustrate this well.

Patient, a male aged 41, very oedematous and dyspnoeic, was admitted after suffering 16 days from an attack of Nephritis. He was only passing 26 ozs. of urine of high specific gravity and his blood pressure stood at 174.

Viscosity	R.B.C.	Hb.	
4.52	4880000	96	Reading at 10.30 p.m.
			Hot air bath begun 10.50 p.m.
4.60	4920000	97	Sweating considerably 11.10 p.m.
4.70	4990000	99	When bath stopped at 11.30 p.m.

12 days later after a course of daily baths the oedema had almost gone and he was passing 130 ozs.of urine.

Viscosity	R.B.C.	Hb.
6.05	5280000	99

Similar results have been recorded by Kundig (1903), Lommel (1904), Brunton Opitz (1906) and Determann (1907).

Hot water baths on the other hand produce a lowering of blood viscosity, while a cold water bath also tends to raise viscosity. That these changes are due to alterations in the water content of the plasma is shewn by the fact that the No. of R.B.C., the Hb. and the Sp. gr. closely follow the alterations in the viscosity (c.f. Meyer 1902 - Zeits.f. diätet und phys. Therap. VI 7) .

The danger of allowing cardiac or vascular cases with an already high blood viscosity to indulge in hot air baths is obvious.

Loss of fluid from perspiration during muscular exercise produces a similar result.

	V.	R.B.C.	Hb.
Average of several examinations	4.22	4200000	86
After severe exertion	4.38	4320000	87

The effect of such loss, of course, is quite temporary and the figures soon return to their original level. Böhme (1910) shews that after brief severe exercise, plasma concentrated by 7 - 8½% increase in albumin, returns to normal within 5 to 10 minutes. Blunschy (1908) found that while short forced work raised blood/

blood viscosity, long continued severe work (ski running) accompanied with just as much sweating produced a lowering of the viscosity.

The amount of blood concentration as measured by the viscosity is suggested as a differential test between organic and functional conditions of the heart (Bachmann 1910). The patients are asked to run up and down stairs several times and the blood is examined a second time. In functional cases the increased viscosity does not exceed .4, but where organic lesions are present the rise is much greater.

The free perspiration associated with raised temperatures in some cases leads to loss of body fluids and high viscosity, e.g.

Case	Temp^{r}.	Viscosity	R.B.C.	Hb.	W.B.C.	
85	100°F	6.88	5100000	100	8800	Aneurism etc.
	97.8°	6.1	508000	100	9600	8 days later.
422	100.2°	6.12	4080000	89	16200	Pleurisy c Effusion, with copious perspiration.
	97.4°	5.02	3690000	82	10600	2 days later.
299	101°	6.20	4900000	90	12800	Pneumonia 4th day.
	96°	4.75	4910000	90	7300	Pneumonia 19th day.

Copious Vomiting and diarrhoea also concentrates the blood plasma and so raise the blood viscosity.

Case	Age	Viscosity	R.B.C.	Hb.	
424	Male 21	11.	7520000	112	Severe Mitral Stenosis with dyspnoea, cyanosis & oedema. Been vomiting for 6 days.
"	"	5.42	5170000	100	12 days later - still some cyanosis and dyspnoea.
"	"	4.7	-	88	5 weeks later - Much improved.
"	"	4.57	4120000	82	7 weeks later - very well now.
469	Male 64	6.0	6130000	90	Arterio-Sclerosis with headache and copious vomiting.
	"	5.502	4950000	82	1 month later - Much better.
210	Male $3\frac{1}{2}$	6.0	4980000	90	Acute gastro-enteritis, 1 day ill. Extreme thirst, constant vomiting and diarrhoea.
		4.12	4290000	86	4 days later - Diarrhoea and vomiting stopped.

The loss of plasma fluid in such cases can be rapidly made good from the tissues or by drinking water.

Venesection and Blood Viscosity.

It is well known that after loss of blood by haemorrhage or venesection the bulk of the circulating fluid is rapidly adjusted by the addition of watery fluid from the tissues. The corpuscles are next made up to normal but the Hb. is much longer in regaining its former position.

These facts are well illustrated in the following case. -

(83) A woman aged 64 with high B.P. and a cerebral haemorrhage of six days standing.

V.	R.B.C.	Hb.	
5.602	5100000	102	Examined at 11 a.m. Bled 10 ozs at 11.30 a.m.
4.61	5020000	90	Taken 3 hours later.
5.1	5570000	92	A week later - Much clearer mentally.

There is an immediate fall of viscosity, R.B.C. and Hb. A week later the R.B.C. have surpassed their former limit, but the Hb. has only increased 2%, the viscosity is still within the normal range.

(344) In a similar case the lasting effect of venesection also comes out.

Patient/

Patient a woman aged 54 suffered from high B.P. and hemiplegia.

	Viscosity	R.B.C.	Hb.	B.P.
Before venesection	5.61	4790000	94%	170
6 ozs blood withdrawn				
49 hours later	5.44	4690000	78%	145
10 days later a further venesection.				
A month later	4.025	4100000	70	163

Welsh (1911) believes that venesection is the only therapeutic method we have for altering the blood viscosity. This is scarcely correct, for drastic purgatives, diuretics, cardiac tonics and oxygen in certain cases can alter blood viscosity, but certainly venesection gives the most permanent result.

Blood Fluids and Blood Viscosity.

Much has been written about the importance of the various cellular elements in the blood while the plasma has received little attention. All the tables shewing relation of Number of R.B.C. to Viscosity could just as well be considered as shewing increase or diminution of the blood plasma. Conditions which remove fluid from the system tend to concentrate the plasma and increase the number of corpuscles per c.m.m. for a time at least. On the other hand, many cases of/

of renal and cardiac dropsy with defective excretion of urine seem to shew a hydraemic condition of the blood, the blood tending to return to normal as excretion is established and the oedema disappears.

The presence of any degree of oedema is associated with a reduction in the viscosity.-

Case	Sex	Age	Viscosity	R.B.C.	Hb.	Urine	B.P.	Remarks.
501	M.	43	3.75	4040000	70	50 ozs.	-	Recurrent Pleuricy $\overline{c}$ Effusion. Great general oedema.
337	M.	72	4.37	3750000	80	20	168	Chronic Bronchitis and oedema.
473	M.	10	4.50	4900000	80	28	92	Acute Nephritis with great oedema.
107	M.	19	4.62	4850000	82	16	120	Aortic and Mitral Incompetence with much oedema.
88	M.	51	4.75	4590000	70	-	160	Aortic and Mitral Incompetence. 30th June.
			Returned to hospital 3rd Aug. - very oedematous.					
	"	"	4.50	5200000	94	38	168	3rd Aug.
			4.75	4520000	94	80	165	1st Sept.

Where cardiac failure and oedema are accompanied by cyanosis a high reading may be obtained, e.g.-

340	M.	58	5.82	5200000	80	-	178	Chronic Nephritis $\overline{c}$ oedema and slight cyanosis.
309	M.	28	5.95	5320000	96	12	-	Chronic Asthma $\overline{c}$ much oedema and great cyanosis.
	"	"	6.25	5170000	100	16	-	Greater cyanosis and dyspnoea. Southeys tubes in use.

Such observations together with those relating to the relative percentage volumes of corpuscles and plasma shew the influence of the amount of fluid in the blood on the viscosity. The amount of blood obtained by ear puncture is insufficient for routine examination of the plasma viscosity, but this was specially examined in a few cases. In these the plasma viscosity ranged from 1.50 - 1.95. Kottmann (1907) gives the normal limits as 1.52 - 2.89, Robert-Tissot (1907) as 1.7 - 2.2. The plasma viscosity is very stable and alters much less than that of the total blood.

Many observers - Burton-Opitz (1902), Rotky (1907), Welsh (1911), and others - think the plasma changes too slight to influence the total viscosity. Kottmann (1907) suggests that changes in the plasma are of importance only in so far as they lead to swelling or shrinkage of the corpuscles. Adam (1909) and Austrian (1911) point out that although the plasma viscosity is low and varies but slightly, these small fluctuations may be extremely important for the total viscosity. This question will be taken up again when dealing with the laboratory experiments.

Leucocytes and Blood Viscosity.

The W.B.C., when normal, constitute such a small fraction of the solid elements of the blood that it would appear unlikely that they could exert any direct influence on the viscosity of the blood. Their plastic character and tendency to adhere to vessel walls or anything which offers a hold would suggest that bulk for bulk they would be more viscous than R.B.C. But the increase of a few thousands would scarcely alter the cellular composition of the blood. In leukaemias where they number hundreds of thousands, a viscosing effect might be looked for. Such cases, however, usually shew a varying degree of anaemia which would tend to reduce the viscosity and so counteract the effect of the hyperleucocytosis. Such was the case in two patients examined.-

Sex	Age	Viscosity	R.B.C.	Hb.	W.B.C.	
F.	29	2.50	2260000	40	10200	Myelogenous Leukaemia 7 months pregnant.
M.	17	4.25	4300000	65	26000	Lymphatic Leukaemia with 75% lymphocytes.

In neither of these is the white count high and the viscosity readings seem to correspond with the reduction in R.B.C. and Hb.

Kottmann/

Kottmann (1907) who thinks the white corpuscles very important, quotes a case of myelogenous leukaemia where the viscosity amounted to 26.48, the W.B.C. being 900,000, the R.B.C. 3140,000 and the plasma volume only 19%. He also notes a high viscosity in the cell free plasma - 2.62 (Normal 1.7). This point is confirmed by Rotky (1907) and by Austrian (1911).

Bachmann (1909) and Austrian (1911) note that in leukaemias the viscosity is usually low, while Robert-Tissot (1907) on the other hand, says that the viscosity generally remains high in spite of the accompanying anaemia.

By giving injections of gelatine, Holmgren (1913) produced an artificial leucocytosis and studied the influence of the W.B.C. on blood viscosity. He concluded that the viscosity was independent of the absolute number of W.B.C., but depended more directly on the relation to the quotient, - Polymorphs / Lymphocytes, the greater the proportion of polymorphs the higher the viscosity. Gullbring (1913) confirms these findings and denies that there is any relation between viscosity and R.B.C. or Hb.

Martinet (1912) and Determann (1914) also notice the hyperviscous effect of leucocytosis, while Blunschy (1908) and Bence (1906) say the while cells are only of importance when they exceed 100,000. Hence/

Hence it will be seen that there is no uniformity of opinion on the subject.

When my records were examined from the side of the viscosity reading, there seemed to be no relationship whatever with the number of white cells, but a rough correspondence appeared when the high leucocyte counts and the leucopenias were separated from the other cases.

Leucopenias.

Seven cases with W.B.C. below 3000 (all Pernicious Anaemias) gave viscosity readings - 2.20, 2.30, 2.37, 2.50, 2.70, 3.75, and 4.50.

Ten cases below 4000 gave readings .- 2.05, 2.75, 3.20, 3.25, 3.92, 4.07, 4.77, 5.25, 6.12. These include cases of Tuberculosis, Typhoid, Pernicious anaemia and Chlorosis.

Twenty-four cases below 5000 W.B.C., range from 2.07 (Pernicious Anaemia) to 6.32 (Chronic Nephritis) and include 3 Beri-Beri Cases.

The figures for Red Corpuscles and Haemoglobin are not given here, but it will be seen at once the conditions are those in which low counts would be expected and these, rather than the leucopenia, sufficiently account for the diminished viscosity. It will be noticed too, that a few of the readings are even above normal in spite of the small white counts.

On/

On the whole a high leucocyte count is accompanied by a high viscosity reading.-

TABLE 7. Cases with Leucocytosis.

Case	Sex.	Age	Viscosity	W.B.C.	R.B.C.	Hb.	Temp.r	Diagnosis.
514	F.	23	2.3	29200	1,540,000	35	99°4	Anaemia of Pregnancy.
519	M.	13	5.12	24600	-	-	101°	Broncho-pneumonia.
300	M.	18	6.12	22900	5,110,000	100	100°	Pneumonia 2nd day.
287	F.	4½	4.47	22000	3,780,000	70	-	Purpura.
404	F.	40	9.75	21500	5,570,000	106	100°	Broncho-pneumonia with cyanosis.
470	F.	36	5.75	19900	4,270,000	90	103.2°	Pneumonia 5th day.
350	M.	19	5.5	17200	4,490,000	80	100.2°	Rheumatic Pericarditis.
289	F.	45	5.47	17200	3,460,000	86	103°	Pneumonia.
432	M.	57	5.75	17100	3,420,000	88	100.4°	Pleurisy (Simple)
238	M.	11	2.75	17000	3,510,000	46	-	Haemophilia.

Fifty-two other cases with leucocytosis ranging from 10.000 to 16,300 embrace a wide field of conditions and shew viscosities from 2.50 (Pernicious Anaemia) to 10.9 (a case with marked cyanosis and vomiting).

With the exception of the three cases in the above table where obvious anaemia exists, all the cases give a reading a little above normal. It will be noticed, however, that they are all febrile conditions with temperatures of 100° F. and over. Again the increase in the Number of W.B.C. does not appear to be accompanied by a proportionate rise in the viscosity.

The facts of the case, then, seem to be these, within ordinary ranges the figures of viscosity and W.B.C. count have no relationship whatever, the apparent association of leucopenia with a low viscosity is readily accounted for by the anaemia present, and the increased viscosity in cases of hyper-leucocytosis by the effects of the accompanying rise of temperature.

Blood Coagulation Time and Blood Viscosity.

Much confusion on this subject existed in the older papers. The increasing thickness of the blood, as coagulation advanced, was pointed to as evidence of a close relationship between the two processes, if indeed they were not one. The introduction of efficient anticoagulants however, has definitely separated viscosity from coagulation.

Little attention has been directed to the question of a possible connection between the two processes and those who have considered it (Trumpp, Welsh, Matschawariani) report that the readings shew no proportionality. On the other hand Buchmaster* states that there is an inverse ratio, the less the viscosity, the greater the coagulation time.

A number of normal and pathological cases were investigated by Addis' Method for estimating the rate of blood coagulation.

Tables have been prepared shewing the cases in order of increasing coagulation time. The corresponding viscosity readings appear to vary in the most haphazard fashion, as the following examples will shew.-

* Buchmaster. p.218 "The Morphology of Normal and Pathological Blood" 1906.

Case	Coag. Time.	Viscosity	R.B.C.	Hb.
269	6 min. 7 secs.	5.16	4590000	96
261	6 30	5.10	4640000	93
	6 50	5.00	4740000	93
267	6 45	4.28	4840000	89
277	6 .5	4.80	4470000	94
	8 40	5.32	4531000	94
276	8 40	5.68	4960000	98
	9 0	6.50	4980000	98
287	10 -	4.48	3780000	70 Purpura.
286	45 min. -	2.75	2610000	53 Haemophilia.

It will be noticed that the conditions shewing the longest coagulation time have viscosity readings much below normal.

A further series of comparative experiments was made by the method of Dale and Laidlaw (1912). The results were very similar to those obtained by the other methods. -

Case.	Coag. Time.	Viscosity.	R.B.C.	Hb.	Diagnosis.
513	1 min. 16 secs.	5.40	3850000	70	Exophthalmic Goitre.
483	1 17	4.50	3900000	81	Diabetes.
489	1 20	3.00	-	-	Puerperal Thrombosis.
570	1 26	4.25	4300000	65	Lymphatic Leukaemia.
481	1 28	2.30	2750000	30	Secondary Anaemia.
485	1 30	6.10	5100000	92	Mit. Stenosis and Cyanosis.
492	1 42	4.45	3650000	72	Carcinoma Sigmoid.
501	1 58	3.75	4040000	70	Pleurisy $\overline{c}$ effusion.
494	2 -	3.70	3070000	59	Acute Nephritis.
525	2 20	1.50	560000	15	Pernicious Anaemia.

From the above selected cases which include the shortest and longest coagulation times, it will be seen that again the slowest coagulation figures are associated with small viscosity readings but that rapid coagulation may occur in either thick or thin bloods.

From the foregoing analysis of clinical cases, information has been obtained regarding some of the factors which influence the viscosity of the blood in the body.

In the majority of cases a parallelism exists between the R.B.C. and the viscosity, increasing viscosity being accompanied by increase of the R.B.C., but except where the red counts are high or very low, the parallelism is not very close. A comparison of the Corpuscular Volume and the Viscosity yields very similar results and an examination of the volume index does not help matters.

A similar relationship exists between the haemoglobin and the viscosity, but again anomalous results are not infrequent.

A better approximation would be obtained by a factor based on both R.B.C. and Hb., for many of the apparent exceptional figures are at once explained when both items are examined, e.g. an unexpectedly low viscosity with a fairly normal count may be due to a low haemoglobin reading.

Since the Specific Gravity of the blood depends chiefly on the haemoglobin content, it shews a similar/

similar fluctuation with the viscosity. Again there are discrepancies which demand explanation. That the gases of the blood are of extreme importance has been demonstrated by examination of cases shewing cyanosis and by observations on samples of blood withdrawn from the body.

Owing to the imperfect character of the methods employed, no connection was found between the viscosity and the alkalinity.

Factors altering the amount of body fluids and so concentrating or diluting the plasma are also of importance, but such changes can be looked upon as altering the number of the corpuscles in unit volume and hence offer no help in finding the influence of the plasma on the total viscosity. A series of examinations of plasma viscosity made at the same time as the ordinary blood viscosity readings, would be of great assistance but it has not been possible to obtain them. It is probable that they might explain the differences in viscosity found in bloods which shew similar R.B.C., Hb., and percentage volume figures.

There is an appearance of a rough correspondence between the viscosity and high or low leucocyte counts. This has been explained as due to other causes, since the/

the leucocytes are usually too small an item to seriously affect viscosity.

The only connection to be observed between viscosity and coagulation time, is that bloods which clot slowly shew a low viscosity reading. This fact is to be accounted for by the anaemia present in these cases.

Blood Pressure and Blood Viscosity.

In health the Blood Viscosity is kept fairly uniform, but in many diseased conditions it may depart far from the normal. The force necessary to propel a fluid varies directly with its viscosity, so that in the absence of interfering conditions, blood viscosity and cardiac activity must move together. If this be so, the heart's action would be increased as the blood thickened and would diminish as the fluid became more watery. Hence we would expect to find hypertrophy of the heart in all its chambers, when high blood viscosity has been present for some time.

In the same way a thickened fluid requires a higher pressure to force it through a uniform outlet, so, other things being equal, a hyperviscous blood must be accompanied by a heightened blood pressure. Conversely a diluted blood would lead to a low blood pressure. One of the most potent causes of arterial degeneration is believed to be a long continued high blood pressure. Hence we would expect to get a high viscosity and a raised pressure associated with arteriosclerosis or at least, present in the pre-sclerotic stages of the disease.

These suppositions demand that the vascular system/

system remains passive and fails to react to the changed conditions. This is extremely unlikely, for the vessels are controlled by a very sensitive mechanism which responds to the slightest stimulus.

Leaving aside the effect of the vessel walls, the blood pressure depends on three principal factors.- cardiac energy, blood viscosity and the sphincter action of the peripheral channels. These factors must interplay so as to maintain the pressure at an approximately constant level, an alteration in one calling forth a change in one or both of the others. From this it follows that one or all of these factors will be affected when the viscosity of the blood is altered.

As it is desirable to save the heart as much as possible while yet maintaining the blood pressure at its proper height, most of the strain of compensation will fall on the arterioles. The amount of flow in a tube is directly proportional to the area of its cross section, so these vessels will dilate to allow the more rapid passage of a viscous blood and will contract to keep up the blood pressure when the fluid is thin. An increase in the diameter of only 20% is necessary to augment the flow by 50%, so that the arterioles should be able to deal easily with any pathological changes in the blood viscosity.

Leonard/

Leonard Hill* remarks that a slight excitation of the vasomotor nerves can alter the flow 100% or more.

The facts, however, may not be so simple. In the larger vessels an alteration in the thickness of the circulating fluid is of little moment, but in the smallest channels its influence is paramount, for the narrower the tubes the greater the effect of the increased viscosity. The result, then, of a high viscosity will be a great increase of resistance in the capillary beds, which may negative the effect of arteriole dilatation and call directly for an increase in the driving pressure. But here again a compensating mechanism exists. It has been pointed out by several observers (and lately by Krogh (1919) in the case of muscle) that in the resting state many of the capillaries are collapsed and only a few are acting. This reserve may be eaten into in compensating for the increased resistance, but the difficulty will again appear when full action is called for.

It is probable that the strain is most felt in the kidney glomeruli.

Still another factor must be considered. The blood plasma possesses an osmotic pressure of about 40 mm. Hg. in virtue of its proteins (6 - 8%)

* Hill. 1907. Recent Advances in Physiology, p.167.

and a slightly greater capillary pressure is necessary to neutralise this and so allow of secretion by the glomeruli. Where increased blood viscosity follows an addition of protein to the plasma, the glomerular pressure must be correspondingly raised and with it the general blood pressure.

The importance of blood viscosity in maintaining blood pressure has been emphasised by Bayliss (1916) who advocated introvenous injections of 7% gum solution in cases of severe haemorrhage. He also demonstrated the rise of pressure that followed when a more viscous fluid was employed in a schema whose driving power continued to deliver an equal volume of fluid.
I have frequently observed a similar rise when blood was substituted for water in a schema under a constant head of pressure.

In view of these considerations it is interesting to note that few authors have found any relation between viscosity and blood pressure. Bachmann(1910) and Welsh (1911) deny that any connection exists. Bucco (1914), Determann (1910) and Trumpp (1911) find some correspondence between high and low figures but none at all at the normal ranges. Blunschy (1909) noted that during exertion the viscosity and blood pressure ran parallel though here the connection is probably/

probably accidental.

Parkes Weber (writing in Allbutt's System) is struck by the almost entire absence of cardiac hypertrophy in cases of polycythaemia, though in one case he found some muscular hypertrophy in the walls of the medium sized arteries (1904).

By intravenous injections of saline, gelatine solutions or blood into animals, Hess (1909) produced an artificial plethora, but after 2½ months no evidence of cardiac enlargement was to be found. Both he and Bence (1906) note that hypertrophy of the heart may be wanting after prolonged blood viscosity increase.

On the other hand, it has been noticed that intra-venous injections of adrenalin by raising the blood pressure, lead to increased transudation from the vessels, concentration of the blood and increase in its viscosity — changes of a temporary nature.

Similar concentration of the blood follows occlusion of veins or obstruction to flow in them.

Müller and Inada (1904), Robert-Tissot (1907), Cheinisse (1910) and Allbutt (1911) on theoretical grounds suggest that increase of blood viscosity may play an important part in the production of vascular disease.

To endeavour to settle the question, my cases have been examined from several points of view.

Long tables have been drawn up shewing viscosity or/

or blood pressure in ascending order and on first glance there appears to be no relationship whatever.

It will be remembered that in the tables shewing normal figures, the cases being arranged in age groups, there was a steady increase of Blood pressure as life advanced, while the viscosity and the blood cells attained a maximum between 30 and 40 and then declined.

Thus the relationship of viscosity to blood pressure varies at the different age periods.

When the records of normal cases are rearranged so that the B.P. readings are in order, a similar relationship holds, the viscosity at first rising with the blood pressure, then later falling a little. The viscosity maximum corresponds to 140 mm. H.g. pressure, and the fall beyond this is got in elderly men.

TABLE 8./

TABLE 8.

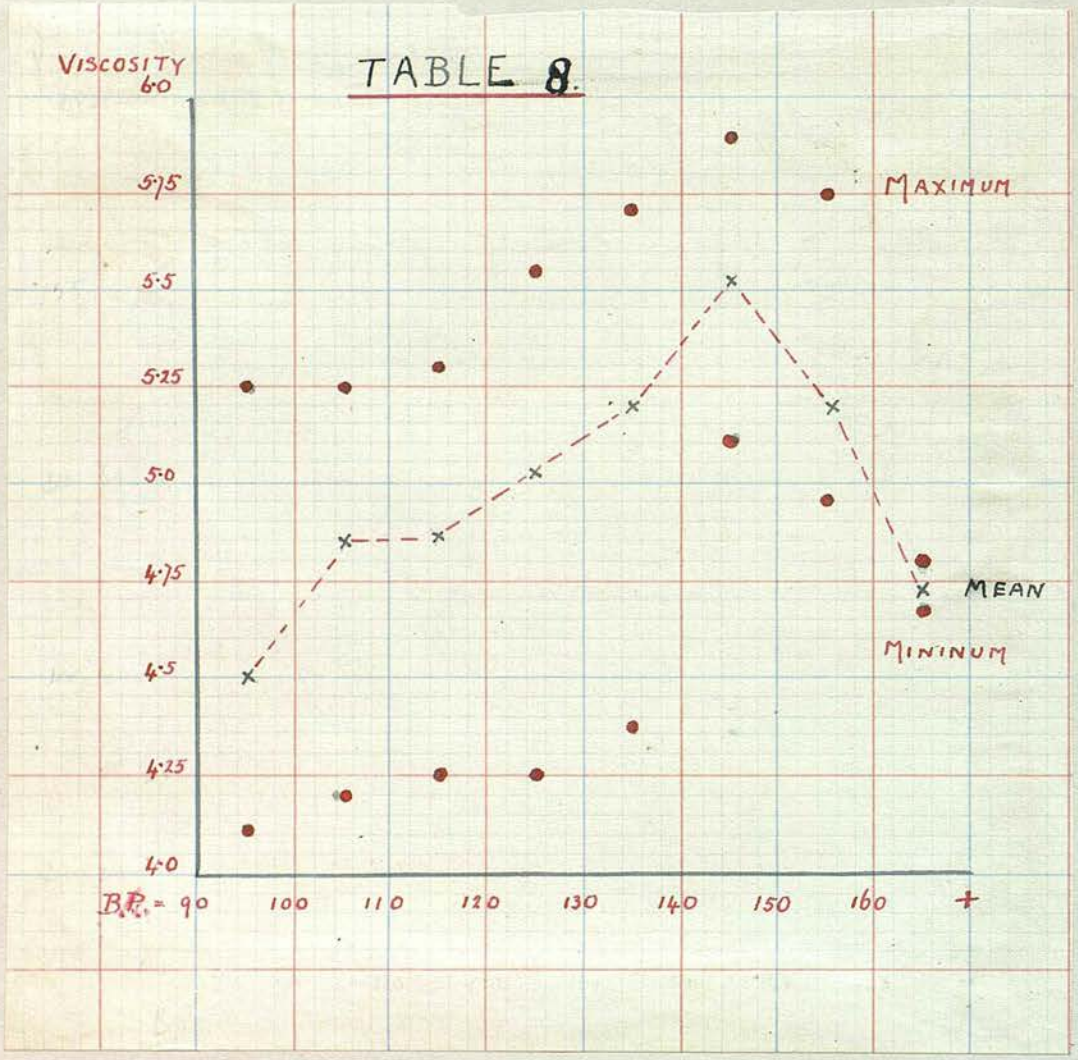

VISCOSITY
6·0
5·75
5·5
5·25
5·0
4·75
4·5
4·25
4·0
MAXIMUM
MEAN
MININUM
B.P. = 90
100
110
120
130
140
150
160
+

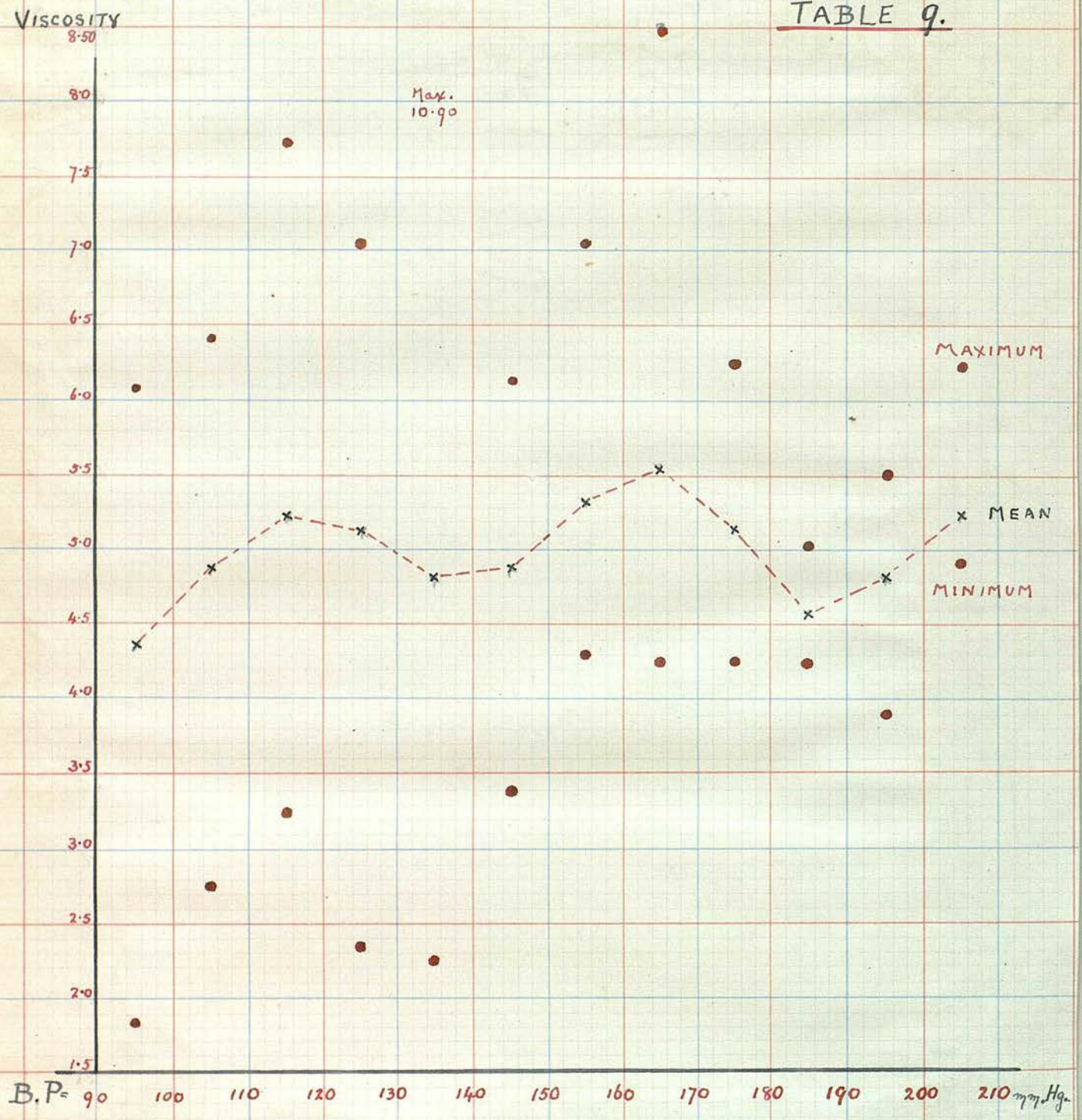
TABLE 8.

Normal Cases - Ages varying.

B.P. mm. Hg.	Viscosity. From - To.	Average.
- 100	4.12 - 5.25	4.50
100+	4.20 - 5.25	4.85
110+	4.25 - 5.30	4.83
120+	4.25 - 5.58	5.03
130+	4.35 - 5.70	5.17
140+	5.30 - 5.90	5.52
150+	4.95 - 5.75	5.2 (All over 60 yrs.)
160+	4.70 - 4.75	4.72 " " " "

The continued increase in "blood pressure" at later ages is to be looked upon as due to an increase in the resistance of the vessel wall with the onset of senile sclerosis, rather than a rise in the actual pressure in the fluid itself. Indeed it is probable that the intravascular pressure actually falls in the later years of life when bodily activity is less.

TABLE 9.


VISCOSITY
8·50
8·0
7·5
7·0
6·5
6·0
5·5
5·0
4·5
4·0
3·5
3·0
2·5
2·0
1·5
Max.
10·90
MAXIMUM
MEAN
MINIMUM
B.P. 90
100
110
120
130
140
150
160
170
180
190
200
210 mm. Hg.

B.P. and Blood Viscosity in Pathological conditions.

TABLE 9.

Pathological Cases.		B.P.	Average Viscosity	Range of V.
14	@	- 100	4.36	1.82 - 6.10
46	at	100+	4.88	2.75 - 6.40
43	at	110+	5.21	3.25 - 7.75
37	at	120+	5.11	2.37 - 7.03
28	at	130+	4.80	2.30 - 10.90
29	at	140+	4.87	3.45 - 6.13
16	at	150+	5.38	4.37 - 7.05
12	at	160+	5.53	4.25 - 8.50
7	at	170+	5.18	4.25 - 6.25
7	at	180+	4.59	4.25 - 5.00
4	at	190+	4.80	3.88 - 5.52
8	at	200+	5.27	4.95 - 6.25

When the pathological cases are arranged in order of increasing blood pressure, no close relationship between the pressure and the viscosity can be found. True the lowest viscosity occurs where the B.P. is under 100 m.m. Hg. but the other average figures seem to vary very little from the normal.

It would be unjust to try to draw conclusions from such a table, for the viscosity averages represent a very wide range of readings. It will be noticed/

noticed, however, that all the lowest viscosity readings are collected in the upper part of the table where the B.P. ranges from 140 downwards. No similar arrangement of the maximum viscosity figures is present.

TABLE 10. High Viscosities.

No. of Cases.	Viscosity.	Average B.P.	Range of B.P.
2	10	137	132 - 142
2	8 +	163	160 - 165
8	7 +	134	118 - 165
4	6.75+	123	110 - 162
4	6.50 +	119	110 - 122
11	6.25 +	126	110 - 160

TABLE II. Low Viscosities.

33 Cases	4.25-4.50	-	95 - 165
10	4.00 +	-	105 - 145
5	3.75	125	118 - 140
5	3.50	132	120 - 140
4	3.25	122	117 - 145
4	2.50	119	95 - 136
3	2.00	118	92 - 135
1	1.82	95	95

The results are again somewhat irregular. Very high viscosity readings may accompany blood pressure figures within the normal range, though practically each series includes both high and low results. In nearly all cases a viscosity of over 6.00 is only a temporary affair due to cyanosis, vomiting or diarrhoea. The last two conditions are often associated with low blood pressure while in cyanosis the pressure may be raised. H. J. Starling* says that even in heart failure the blood pressure does not fall, but is normal or even high.

When we examine the low viscosity cases the connection seems more evident, for as the viscosity falls from 3.50 there is a regular drop in the pressure and in no case is a thin blood associated with a blood pressure above normal.

The lowest cases in this series are all anaemias of one kind or another, while a little higher up the list appear a number of nephritis cases with oedema, which would account for the higher blood pressures found.

No more exact relationship is to be found when individual cases are followed over considerable periods.

* H. J. Starling 1906 Lancet Sept. 29th.

An arteriosclerotic aged sixty years, examined at weekly intervals, shewed B.P. readings of 200, 198, and 210, while the Viscosity ran 4.75, 5.25, 5.30.

An aortic and mitral case (aged 51) in a state of failure of compensation, gave B.P. 160 , V. 4.75, two months later on readmission to hospital in a very oedematous condition, the figures were B.P. 168 and V. 4.50. A month later when much improved the B.P. was 165 and the V had risen to 4.75.

Sometimes the Blood pressure is kept more constant than the viscosity, e.g. on three occasions a double aortic patient had a B.P. reading of 140 while the viscosity was 5.50, 4.95, and 5.1. Or again the viscosity may remain nearly constant while the pressure varies, a patient convalescent after an operation for varicose veins shewed B.P. 142, V. 5.20; B.P. 130, V. 5.10; B.P. 112, V. 5.05.

It has been noted already that at each level of blood pressure there is a range of viscosity greatly in excess of normal. Taking the limits of normal viscosity as 4.70 - 5.73 and those of Blood pressure as 120 - 150 m.m. of Hg., the cases naturally divide themselves in normal, high and low values and so form nine groups.

These have been worked out with the following results.-

GROUP A. /

GROUP A.

V+ , B.P.+ .

High Viscosity and High Blood Pressure. Cases shewing marked cyanosis and cardio-vascular disease, - Mitral Incompetence, Aneurism and chronic bronchitis, all with cyanosis.

GROUP B.

V+ , B.P. =.

High Viscosity and normal pressure. Contains both cardiovascular and respiratory cases and is intermediate between "A" and "C".

Valvular and arterial cases, cerebral haemorrhages especially with slight cyanosis present.
Acute Pleurisies, Convalescent Phthisis and Bone Tuberculosis cases. Gall-stones, Tabes, Neurasthenia and a few nephritis cases.

GROUP C.

V+ , B.P. - .

High Viscosity, low blood pressure. Pulmonary Insufficiency and malaeration of the Blood. Mostly lung conditions - acute/

Acute Pneumonias, Pleurisies with effusion, Carcinoma of the lungs, Phthisis, and other tuberculous lesions. Asthma and Mitral Stenosis with Cyanosis, Pernicious Anaemias, Varicose Veins and Diabetes.

GROUP D.

V - , B.P.+ ,

Low Viscosity and High Blood Pressure.

Renal insufficiency and Hydraemia.

Acute Nephritis with oedema, Aortic Stenosis, Mitral incompetence, aneurism and arterio-sclerosis without cyanosis but with some oedema. Cirrhosis of the liver with jaundice.

GROUP E.

V - , B.P. =.

Low Viscosity with normal pressure.

Another intermediate class containing cases typically belonging to D or F.

Many nephritics where oedema is present.

Pernicious and other anaemias.

GROUP F.

V - , B.P. -.

Low Viscosity and Low Blood Pressure.

Anaemias - both pernicious and others.

Also some oedematous nephritis cases.

GROUP G.

V = , B.P.+ .

Viscosity normal, Blood pressure high.

Cardiovascular and renal cases without cyanosis.

Cerebral haemorrhage, arteriosclerosis, and heart failure with some oedema.

Subacute and chronic nephritis cases.

GROUP H.

V = , B.P. -.

Normal Viscosity and low blood pressure.

Convalescent Pneumonias and Pericarditis.

Pleurisy with effusion and mild cases of mitral stenosis.

GROUP I.

V = , B.P. =.

Normal viscosity and blood pressures.

This group contains besides normal cases many where oedema and cyanosis are both present and are neutralising each other.

From this arrangement it will be seen that there are four prominent classes.- (1) Cases of cyanosis, (2) Pulmonary insufficiency cases, (3) Hydraemias, (4) Anaemias.

Renal/

Renal cases appear in several of the groups according to the presence or absence of oedema and the degree of increased pressure.

Martinet (1912) divided his cases into three classes by means of the ratio $\frac{BP}{V}$. He worked with Hess' viscosimeter and a Pachon oscillometer and found as normals V = 3.8 - 4.5 B.P. 130 - 170. This gave a range of normal values for his quotient $\frac{B.P.}{V}$ of 38 - 45. (Making allowances for the different instruments employed - my figures would be V = 4.8 - 5.3 B.P. 120 - 150 which would give $\frac{B.P.}{V}$ = 20 - 30. This factor has been worked out for the normal cases and will be found on page 30.)

Cases that have a blood pressure reading comparable to their viscosity reading he designates "eusystoliques". They include normal cases, cases with low and cases with high readings.

The high tension cases with viscosity and pressure both raised he calls plethorics. He believes they have no renovascular disease though they may be in the pre-sclerotic state. This class also includes diabetic, obese and gouty subjects.

It will be noticed that he includes no cases such as appear in my "A" group.

The low tension "eusystoliques" are cases of anaemia (my group F.)

Cases/

Cases that lie outside the limits of $\frac{B.P.}{V}$ = 38 - 45 are abnormal.

"Les Hypersystoliques" where $\frac{B.P.}{V}$ exceeds 45, that is, where the pressure is high but the viscosity low, have all got cardio-renal disease, temporary or permanent, with hypertension and hydraemia, and haemorrhages are to be looked for.

"Les Hyposystoliques" have $\frac{B.P.}{V}$ under 38 - a low pressure with a comparatively high viscosity - are mostly cases of cardiac or pulmonary failure.

These findings correspond closely with those given above.

To sum up. It would appear that viscosity and blood pressure are related to each other. A certain viscosity is necessary for the correct maintenance of blood pressure and changes in the thickness of the blood will tend to alter the pressure, conversely changes in the blood pressure will tend to dilute or concentrate the blood.

In health a parallelism can be demonstrated between these two factors but under disease conditions they do not necessarily follow each other. This is due to the capacity of the body to compensate for wide changes of one or other, and allow a rapid return to normal.

The readings fall together in anaemias and mount together in cyanosis, while they tend to move in opposite directions in cases of acute renal or pulmonary inadequacy.

Pulse Rate and Viscosity.

I have been able to find no reference to this subject in the literature except that of Nicholls (1896) who believes the effect of viscosity on the pulse rate is too small to be of any importance. The pulse rate varies so greatly and so rapidly that probably little attention should be paid to it so long as it is within normal limits. In some individuals the figures vary in the same direction.-

A case of mitral stenosis with much cyanosis gave the following figures.-

3 April	V = 11	Pulse 72	
17 "	5.35	68	Much improved.
25 May	4.70	56	Returned to normal.

A case of diarrhoea and vomiting shewed the high readings of V = 6 Pulse 140 while the symptoms lasted, but these fell to V = 4.15 Pulse 94 in a few days when he improved.

The variations are not always parallel as the following case shews.- No.483, a diabetic, examined on May 30, gave V = 4.50 Pulse 84, on June 4th V = 4.75 P. 50, and on June 14th V = 4.55 P. 72.

The following results are of interest.

A/

A woman, aged 64, had a cerebral haemorrhage on June 23. She was examined first on the 29th when the viscosity of the blood was found to be 5.62, the pulse rate 96 and respirations 24. The Blood pressure was high, so 10 ozs. of blood were withdrawn. Three hours later the readings were V 4.61 P. 90 R. 24, and after a further week V 5.12 P. 80 R. 20.

All cases shewing abnormally high or low pulse rates were collected and arranged according to the degree of viscosity they shewed.

Rapid Pulse (over 100), High Viscosity.

Cases shewing a rapid pulse and a high viscosity include cardiac failures, cyanosis cases, pneumonias, asthma, diarrhoea and vomiting.

Rapid Pulse, Low Viscosity.

A rapid pulse with a low viscosity occurs in all varieties of anaemias, pernicious and secondary anaemias, leukaemia, haemophilia, acute rheumatism, malnutrition, malignant disease, etc. where the haemoglobin is low.

Rapid/

Rapid Pulse, Viscosity normal.

An intermediate group where normal viscosity accompanies rapid pulse includes pneumonias, pleurisies and cardiac failures with oedema.

Slow Pulse (under 65). High Viscosity.

Cases of cardiovascular disease with only slight cyanosis, and chronic nephritics.

Slow Pulse and Low Viscosity (in none of these is the Viscosity very low.)

A mixed group containing compensated mild mitral stenosis, diabetes, myxoedema, hemiplegia, abdominal tumour with jaundice and a chlorosis.

The remaining cases with a slow pulse were mostly mild heart and kidney cases.

The cards were then rearranged and all shewing high or low viscosity readings were examined as to the pulse rate.

High Viscosity Cases.-

Only about half of the cases shewing viscosity readings over 6.00 were accompanied by a rapid pulse. These consisted for the most part of cyanosis cases, heart/

heart failures, cerebral haemorrhages and pneumonias, yet some of the most severe cases had a pulse of normal rate.

Low Viscosity Cases.

This group which consists of anaemias with viscosity readings under 4.00, shewed no cases with slow pulse. Again in about half the cases the pulse rate was distinctly high, while in the others it was normal.

From this it will be seen that changes in the direction of either increase or diminution of the blood viscosity are never associated with a reduction of the pulse rate. Both abnormalities alike embarrass the circulation and call for an increased rapidity of the heart's action, in the one case to keep the thicker blood in motion and in the other to endeavour to maintain the blood pressure at a working level, constriction of the peripheral channels having failed to do so.

Respiratory Rate and Blood Viscosity.

As in the last Case, tables were drawn up under the headings of high and low figures for viscosity and respiratory rate, and the results found were very similar. This is no doubt due to the fact that in many cases the respiratory and pulse rates tend to move together.

The Rapid Respiration Rate and High Viscosity group included pneumonias, cardiac cases with cyanosis and moribund cases.

The combination of a low viscosity and rapid breathing was characteristic of many cases of anaemia.

When examined from the side of the viscosity readings the relations were less obvious, though it was striking that the two lowest anaemias shewing viscosity readings of V = 1.50 and V = 1.82 had respiratory rates of 36 and 28 respectively.

Effect of Pathological Temperatures on the Blood Viscosity.

The Viscosity of all fluids becomes reduced as the temperature is raised, the change being most marked in denser solutions. Kagan (1911) working with an average sample of blood calculated that its viscosity fell .8% for each additional degree of Temperature between 17° and 37°C. Graham Brown (1894) found that by raising the temperature of defibrinated blood from 96° - 107.6° F. its viscosity fell 10% and argued that if similar conditions obtained in the body the heart work would be correspondingly reduced and the febrile temperature would be a boon to the organism. This effect would be further enhanced by the capillary dilatation which often accompanies fever.

No doubt a diminished viscosity, did it occur in such cases, would be of great benefit, for the heart is often poisoned by toxins and its action weakened in consequence. But this result is seldom found, the viscosity in febrile conditions being usually raised. Robert-Tissot (1907) makes the suggestion that the factors are reversed, the rise in temperature being due to increased friction from alteration in the total size of the corpuscular mass. A similar statement was made by Stephen Hales (in 1733) who also added that the cold fit of ague was caused by the blood becoming too viscous. These authors must never have seen a case of polycythaemia where enormous increase in the corpuscles is unaccompanied by fever.

TABLE 12. Cases shewing fever.

Case	Sex.	Age.	Temp^{r}.	Viscosity	R.B.C.	Hb.	W.B.C.	Remarks.
511		14	106.4°	5.75	4080000	72	13400	Acute Meningitis.
523	M.	31	105°	7.4	4320000	90	15000	Pneumonia 3rd day.
467	M.	24	104.2°	6.88	4790000	92	10300	Cirrhosis etc.
518	M.	15	104.2°	5.5	-	-	-	Meningitis (Pneumococcal)
288		27	104°	5.62	-	85	16100	Pneumonia.
524	M.	35	103.2°	4.25	3530000	69	10500	Acute rheumatic fever.
289	F.	45	103°	5.47	3460000	86	17200	Pneumonia.
470	F.	36	103°	5.75	4270000	90	19900	Pneumonia.
210	M.	$3\frac{1}{2}$	103°	6.00	4980000	90	10400	Diarrhoea and Vomiting.
413	M.	39	102.8°	5.87	4700000	92	10600	Pneumonia.
347		11	102.4°	4.85	-	78	8400	? Pm.
459	M.	65	102.2°	5.9	5090000	100	15500	Pneumonia.
369	M.	23	102.2°	5.75	4750000	70	11000	Pneumonia (? T.B.)
417	F.	30	102.2°	5.03	4650000	80	8000	Ascites.
495	F.	20	102.2°	4.05	2810000	70	15000	Acute Rheumatism.
362		31	102°	4.48	3500000	60	16000	Unresolved Pneumonia.
435	F.		102°	4.55			13700	Double Pneumonia (7 months pregnant.)

TABLE 12. (Continued.)

Case	Sex.	Age.	Temp^{r}	Viscosity.	R.B.C.	Hb.	W.B.C.	Remarks.
341	F.	22.	101.6°	4.00	4650000	46	90000	Phthisis.
503	F.	20	"	5.02	3250000	63	12200	Acute Rheumatic Fever
498			"	4.75				
402	M.	15	101.4°	5.90	4900000	84	6000	Pleurisy with Effusion.
429	M.	24	"	4.55	4930000	76	-	Pleurisy with Effusion.
427			"	4.72	4560000	78	8700	Acute Rheumatism.
392	M.	49	101.2°	4.95	4970000	85	8400	Pleurisy with Effusion.
299		42	101^{d}	6.20	4900000	90	12800	Pneumonia 4th day.
519		13	"	5.12	-	-	24000	Pleurisy and Broncho pneumonia.
482	M.	71	"	4.50	3840000	65	8000	Chronic Bronchitis and Rheumatism.

The accompanying table (No.12) contains those cases who had a temperature of 101° F. or upwards. An examination of it will shew that the fever is usually associated with some increase in the blood viscosity. This, however, is by no means constant and the two sets of figures are in no way parallel. Some of the lower viscosity readings may be explained by the lower blood counts, but here again it will be noticed that the viscosity is often relatively high when compared with the number of red corpuscles present.

It is striking that at each range of temperature the pneumonias give much higher figures than the acute rheumatisms and the pleurisies with effusion.

The high viscosity of fevers might be attributed to the free perspiration so frequently present, causing concentration of the blood. This is unlikely, since only one of the cases (No.459) shews a high R.B.C. count, the others tending to be rather below normal. This concentration would be expected above all, in acute rheumatic fevers where copious sweating is the rule; instead, the readings of viscosity, as well as those of the red corpuscles and haemoglobin, are lower here than in any other condition.

The special increase in pneumonias might suggest that the change was due to some increase in the CO_2 content/

content of the blood - a view favoured by many who have sought to explain the condition. This may be so, but it takes a much greater anoxaemia in cardiac cases to produce similar results, and something further must be sought for to explain it. It is commonly said that in pneumonia the plasma is richer in fibrinogen. (Osler says it may rise from 4 to 10 parts per thousand.) Other febrile conditions also cause a similar, though less marked, fibrinogen increase and it is generally proportionate to the leucocytosis.

The table does not support the belief of some observers that the viscosity bears a relation to the number of white corpuscles present.

It is possible that retention of chlorides which is more marked in pneumonia than in other fevers, may have something to do with the viscosity increase.

Another explanation is that there may be an increased hydration of the colloid particles with corresponding reduction in the amount of the more fluid portion of the plasma. Wells, in speaking of inflammatory oedema (p. 350) says.- "there is undoubtedly an excessive formation of metabolic products in the tissues and the asphyxial conditions in inflamed tissues favour acid formation which may cause in the colloids an increased affinity for water."

It may be concluded then, that the high viscosity of/

of the blood in fevers is not due to free perspiration, but to some product of altered metabolism, of which the raised temperature itself is only another manifestation.

Thirty-three further cases with temperatures under 101° F. were also examined with similar results. Again the pneumonias head the lists, the contrast with other cases being even more obvious at the lower temperatures.

The factors which influence Viscosity.

Of late years much attention has been devoted to the study of viscosity by workers in pure science, and the knowledge of the subject has made great strides. Apart from its academic interest, viscosity has proved of considerable assistance in physical, organic and inorganic chemistry in settling points where chemical evidence was not available. Above all, the viscosity is the most delicate guide to the changes which take place in colloids under various conditions.

The blood consists of solid elements - the corpuscles, suspended in a fluid - the plasma, which itself is a complex mixture of colloids, crystalloids and non-electrolytes in water. To understand the factors which may influence viscosity, it is necessary to glance at some of the facts of modern colloidal chemistry.

Fluids, other than pure solutions, can be regarded as Dispersoids - mixtures of solids, liquids or gases in each other. No sharp boundaries exist between the different types of disperse systems which only vary in the degree of dispersion and the size of their particles. The following arrangement is based on the writings of Burton (1917) Ostwald (1917) and Zsigmondy (1917).-

Molecular Solutions.	Colloidal Solutions.		Mechanical Suspensions.
Size of particles -			
from 0.1 u u - 1.0 u u	from 1.0 u u - 0.1 u (100 u u)		from 0.1 u (.001 mm) - 1.0 mm.
Diffusible	Non-diffusible		Do not pass through filter paper.
Dialysable	Non-dialysing		Settle with gravity.
Filter passing	Hydrophilic	Hydrophilic	
"Crystalloids"	"Emulsoids"	"Suspensoids"	"Fine and Coarse Suspensions"

All these "systems" consist of two "phases". The fluid portion or pure solvent is variously known as the "Dispersion Means", "External phase", Continuous Phase", "Dispersing Medium" or "Continuous Menstrum". The other portion consists of many isolated particles separated from each other by the solvent and is termed the "Disperse Phase" or "Internal Phase".

Colloids, with which group we are most concerned, are of two kinds, suspensoids (suspension colloids) and emulsoids (emulsion colloids). The former consist of a solid disperse phase in a fluid medium, the latter are a combination of two liquids. Most proteins belong to the emulscid class of colloids.

The viscosity of such disperse systems must depend on many things - "the internal friction of each of the several phases, the surface tension and the surface friction of the internal surfaces, the density of the electrical charge at the internal surfaces, the shape of the particles and the nature of the particles as to the absorption layer and probably the degree of dispersion." (Burton p. 161).

One of the principal factors is the size of the ultimate elements which rub against each other, for on this depends the total frictional surface. This point is strikingly illustrated by Starling (1909 p.13) "A sphere of 10 c.c.m. would have a surface area of 22 sq. c.m. Reduced to a fine powder of spherules, /

spherules, each .000 000 25 c.m. in diameter, the total surface of the solid would be nearly half an acre (20,000,000 sq. c.m.)". Similar calculations are given by Philip (1913, p.220) and by Ostwald (1917 p. 118.)

Thorpe and Rodger (1894) proved that viscosity may be looked upon as the attracting force between the molecules, but Jones (1907) believes that it is really a property of the atoms of which the molecules are composed.

The Viscosity of One phase Systems. The work of Thorpe and Rodger constituted a great advance in the knowledge of the viscosity of simple liquids. They examined at different temperatures, a large number of pure substances - members of homologous series, - and found values for - H, - CH_2, - OH, etc. From the data so obtained, the viscosity of a compound can be calculated with fair accuracy.

The Viscosity of Two phase Systems. Where two substances, entirely indifferent to each other, are mixed together the viscosity of the solution may follow the law of mixtures and depend on the relative amount of each component present. More frequently the matter is not so simple, for few solutions are mutually indifferent. The viscosity in such cases shews either a maximum or a minimum point, depending on whether the fluids/

fluids tend to combine or to dissociate each other.

The Viscosity of Molecular Solutions.(Crystalloids) The study of this subject has been fraught with many difficulties. When salts are dissolved in water the different constituents may not be uniformly arranged. For example, it is impossible to tell the proportion of "(a) simple water molecules, - H_2O; (b) associated water molecules, assumed to be triple $(H_2O)_3$; (c) ions, hydrated to an unknown extent; (d) undissolved molecules, possibly combined with water; (e) and in strong solutions - salt complexes." (Dunstan and Thole (p.59) quoting Applebey - Trans. Chem. Soc. 1910, Vol. 97, p.2000.) Further, the proportions of these will vary with the temperature and the concentration.

Most salts in solution increase the viscosity, a few, however, produce a "negative viscosity".

In solutions of electrolytes, viscosity and conductivity are closely related, the latter increasing as the former diminishes.

The Viscosity of Suspensions.- According to Einstein (1906)* the viscosity of a suspension of rigid particles is simply proportional to the aggregate volume of the suspended spheres. This was confirmed by Hatschek (1910) who showed that the viscosity was independent of the size of the particles. Bingham (1911) makes/

* Einstein 1906 Ann. Physik. (19) p.289.

makes a similar statement. In 1916 Humphrey and Hatschek re-examined the question and found that in concentrations of 2.6% of suspended matter the particles did interfere with each other and the viscosity also depended on the rate of shear, which was more marked at higher concentrations.

The Viscosity of Emulsoids is a much more complex question than the foregoing. In the case of emulsoids the following factors must be considered, - the temperature, the concentration and the amount of dispersion, the amount of "solvate" formation, the influence of added electrolytes and non-electrolytes, the electric charge of the system, and the presence of more viscous colloids.

Previous mechanical or thermal treatment and the ageing of the colloid are also important in laboratory work.

In contrast to suspensoids and molecular dispersoids, the viscosity of emulsoids even in weak solutions is much greater than that of the disperse means, and its viscosity falls rapidly with increasing temperature.

As concentration increases, the viscosity of an emulsoid rises slowly till it reaches a critical point, after which the rise is very rapid. It has been calculated that where the particles remain spherical they/

they will touch each other when their volume reaches 70%. Concentrations above this are only possible where the particles can be deformed and flattened. (Hatschek 1911)

The degree of dispersity is also of importance. Ostwald (1915) has shewn that a coarse mixture of castor oil in water scarcely alters the viscosity, but the addition of something which will aid dispersion (e.g. a little gum) will raise the viscosity enormously, far above the viscosity of either the pure oil or gum solution alone.

Particles of the disperse phase are wetted by the continuous phase, a covering of which remains permanently attached to the particle and this combination of particle and envelope is known as a "solvate". The amount of solvate formation varies greatly in different solutions and influences the viscosity considerably.

Perhaps akin to this, is the fact that the presence of small quantities of a more viscous colloid may enormously raise the viscosity of the whole mixture.

Added crystalloids in relatively small amounts produce very varied effects. Non-electrolytes (sugar, urea, alcohol) in low concentration only alter the viscosity to the extent they influence the viscosity of the pure continuous phase, in greater concentrations they may cause perceptible non-additive changes.

Emulsoids/

Emulsoids are extremely sensitive to the action of electrolytes, mere traces of which may enormously influence the viscosity of the solution. Mann* (p.17) remarks that it is "the electrolytes which put life into the proteins". The effect depends on the state of the protein. Neutral salts always lower the viscosity of neutral protein, and usually of acid protein too, while with alkali protein viscosity may be raised. Bottazzi (1913) shewed that the viscosity of a protein was least when it was non-ionic and uncombined and that the addition of a small quantity of either acid or alkali raised the viscosity enormously. The great increase is due to the increase in the number of dissociated (electrically charged) colloid particles and there is a general parallelism between the concentration of -OH ions and viscosity (Ostwald 1915). Hence the electrical charge of the disperse phase is very important for viscosity. Ostwald says that most colloids have already an electric charge towards their disperse means, but Hardy (1905) and Robertson (1918) state that the pure serum proteins are electrically inactive and derive their activity from attached electrolytes.

The Plasma Constituents and Viscosity.

The plasms may be looked upon as a mixture of various emulsoids in water, together with many added/

* Mann 1906 "Chemistry of the Proteins".

added electrolytes and non-electrolytes. A consideration of the foregoing facts will suggest how complicated the factors influencing the viscosity of such a mixture must be.

The solids of the plasma amount to roughly about 10%, and of this, the proteins constitute fully 6 - 8%. By salting out and other processes, the various protein fractions can readily be separated (though the work of Hardy (1905) and of Michaelis and Rona (1910) suggests that these fractions are merely parts of a large protein complex and do not pre-exist in the serum.)

The various serum proteins, in as pure a state as possible, have frequently been employed by those studying the conditions influencing the viscosity of emulsoids, and much of the general description given above has been based on these observations.

With regard to the relative value of these proteins there is less information available. Determann (1908) noticed that globulin was more viscous than serum albumin and para-globulin, and Ostwald(1910) arranged the serum proteins in order of ascending viscosity - albumin, pseudoglobulin, euglobulin, fibrinogen. Chick and Lubrzynska (1914) examined the relative viscosities of the proteins of horse serum, and obtained similar results. They found that with solutions of 10% protein, the viscosity of the/

the euglobulin solution was 3 times greater than that of the pseudoglobulin and six times more than the albumin solution, the ratio, however, varied with the concentration, being much greater in denser mixtures. (e.g. at 20%, pseudoglobulin was 5 times as viscous as albumin)

In low concentrations the viscosity of serum albumin solutions was scarcely above that of water, but at higher concentrations it rose more rapidly. The effect of temperature, too, was only slight until high concentrations were reached. They conclude that in amounts less than 10%, serum albumin behaves almost as a crystalloid.

Euglobulin solutions on the other hand exhibited comparatively high viscosities at low concentrations and the influence of temperature was much more marked.

Pseudoglobulin stood intermediate in its properties. As the globulins constitute the larger part of the total serum protein, and they are so much more viscous than the albumin, they must be the chief cause of the plasma viscosity. Chick suggests that even a small amount of euglobulin would exert an undue influence on the total viscosity.

These facts are of importance when it is remembered that globulin may (relatively and absolutely) increase in certain conditions (e.g. during starvation - Glaesser (1905), and in the course of immunisation - Gibson/

Gibson and Banzhaf (1910).)

Euglobulin is present in the plasma as a compound with NaCl and this salt globulin has a lower viscosity than the corresponding alkali or acid combinations of equal strength and equal-O H ion content. (Chick 1914)

To test the relative effects of the different serum proteins on the blood viscosity, some ox blood was obtained and allowed to clot. The various protein fractions were then separated by half and full saturation with ammonium sulphate. They were then dialysed for 14 days against distilled water under toluol. The amount of protein in each fraction was estimated by evaporating a measured quantity and weighing the residue. A series of weak solutions of equal protein value was then made up with sodium chloride and distilled water to form isotonic mixtures.

Equal amounts of washed red blood corpuscles were added to a sample of each of these solutions. When measured in the viscosimeter the following results were obtained. -

Euglobulin mixture	50.5 Secs.
Pseudoglobulin "	48.4 "
Remaining Albumins	47 "

These figures confirm the findings of Ostwald and of Chick.

Some/

Some workers have sought to find a parallelism between the plasma viscosity and the protein content of the fluid. The results have been disappointing, chiefly because the protein has simply been estimated as Nitrogen by "Kjeldahl". This would overlook the relative amounts of globulin and albumin present, an even more important matter than the total quantity of protein.

The question of the concentration and dilution of the plasma by loss or retention of body fluids has already been considered.

The plasma viscosity is scarcely above that of pure water, and to obtain reliable measurements it is necessary to use a great amount of blood and a larger instrument than is available clinically. This may account for the fact that the viscosity of the plasma has received very little consideration. It has been stated by some observers that the plasma viscosity is very stable and much less liable to fluctuate than that of the whole blood. But the figures are small to begin with, and slight alterations would be difficult to observe with the ordinary instruments employed.

The normal limits of plasma viscosity range from 1.49 to 2.89, though individual authors give a much narrower fluctuation. In a few cases I specially examined/

examined (not normals) the viscosity of the plasma was found to vary from 1.50 - 1.95 and did not bear a constant relation to the total blood viscosity.

The views as to the importance of plasma viscosity are many. Welsh (1911) states that it does not vary sufficiently to make it a factor in influencing the total viscosity. A few observers (Hirsch and Beck 1901, Rotky 1907, and Bachmann 1908) grant that it may have a slight importance, though far inferior to that of the corpuscles. A more prominent position is given to it by Adam (1909), Austrian (1911) and Trumpp (1911); but they fail to appreciate its full significance. Josué and Parturier (1916) suggest that it may have a double action on the viscosity of the whole blood.- (A) The plasma viscosity is the point from which the corpuscles start to raise the total viscosity (an additive conception) and (B) The effect of the corpuscles will be greater in a more viscous medium. The only author who appears to have got a true estimate of the question is Trevan (1918) who applies Hatschek's findings to the case.

Many attempts have been made by workers in physical chemistry to produce a formula which would express the influence of solid particles on the viscosity of the fluid containing them.

Most of the linear formulae suggested have been unsuccessful since they are only applicable over a small/

small range of concentrations. The most satisfactory results are obtained by employing Hatschek's (1910) formula which is a modification of one by Einstein (1906).

$$V^{o} = V\ (1 + 4.5\ F\ ) \qquad (1)$$

Where V^{o} and V are the viscosity of the whole fluid and that of the continuous phase respectively and F is the ratio of the aggregate volume of the solid particles to the total volume of the mixture.

From this expression the startling fact appears, that the viscosity of the mixture is independent of the size and degree of dispersity of the particles, but depends on the viscosity of the original fluid and on the relative volume of the two phases -in technical language it is a linear function of the disperse phase. This only holds good for low concentrations and for fairly coarse particles.

For concentrations over 50% he introduced another formula (1911)

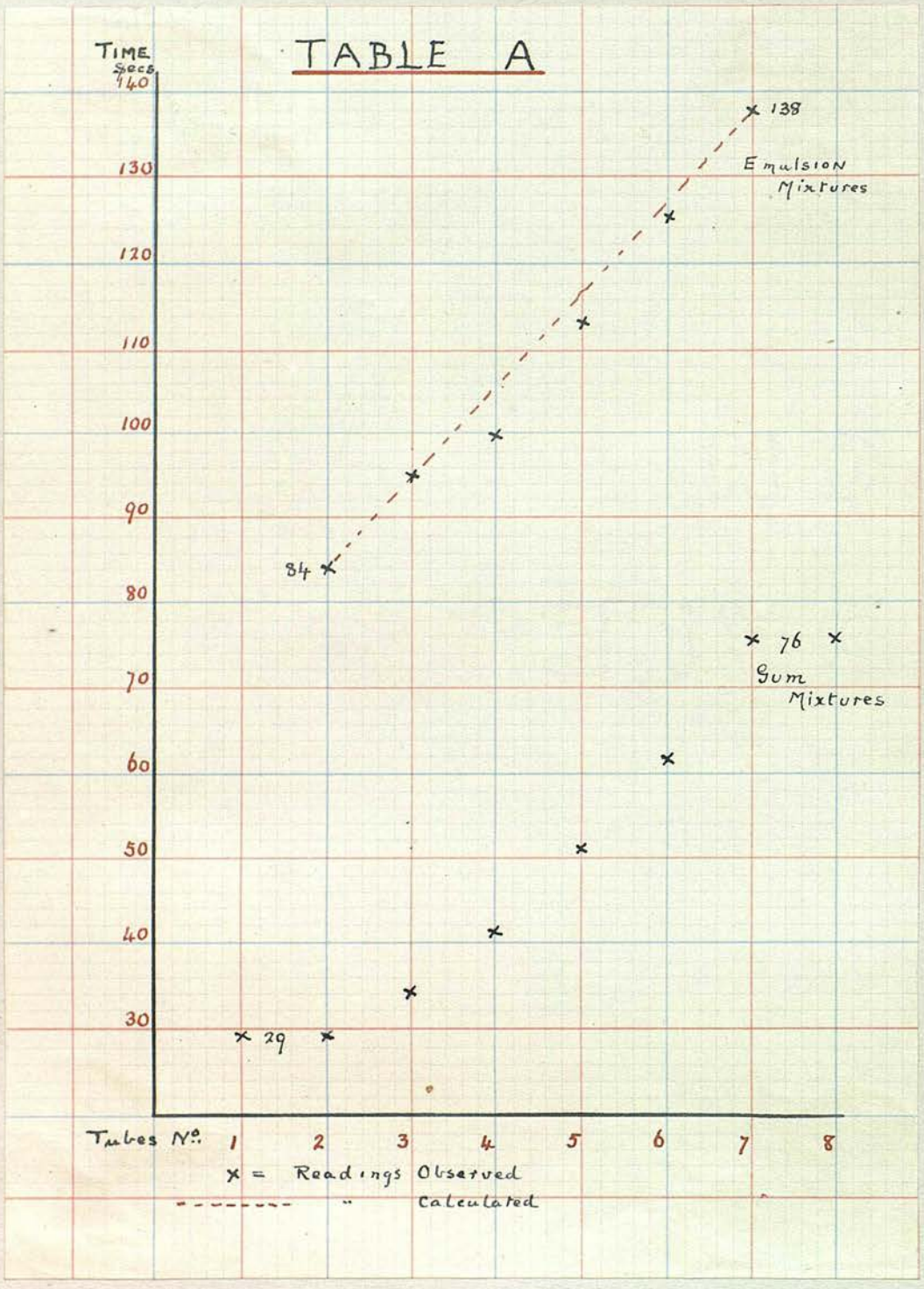
$$V^{o} = V\ \frac{\sqrt[3]{A}}{\sqrt[3]{A} - 1} \qquad (2)$$

Where A is the ratio - volume of system / volume of disperse phase. This expression allows a much more rapid rise in viscosity as the concentration approaches 70% where the spherules touch each other.

Hatschek shewed in 1912 that his formulae were applicable to emulsoid fluids and to systems where the solids were deformable.

These/

TABLE A


TIME Secs
140
130
120
110
100
90
80
70
60
50
40
30
138
Emulsion Mixtures
84
76
Gum Mixtures
29
Tubes No:
1
2
3
4
5
6
7
8
x = Readings Observed
---------- " Calculated

These laws express the influence of the amount of solids in the plasma on the plasma viscosity, and also the part played by the corpuscles and the plasma in the viscosity of the whole blood.

A large number of experiments were carried out to test these points.

To find the influence of the plasma on the viscosity of the whole blood a series of mixtures was made, containing equal quantities of red blood corpuscles in isotonic gum solutions of various concentration.

TABLE A.

Tubes	1	2	3	4	5	6	7	8
(A) Emulsion	-	10	10	10	10	10	10	-
(B) Saline	20	10	8	6	4	2	-	-
(C) Gum Solution	-	-	2	4	6	8	10	20
(D) "Plasma" Viscosity	29	29	34	40.5	50.7	61	76	76
(E) V^{o}/V =		2.89	2.72	2.42	2.19	2.05	1.9	
(F) Total Viscosity		84	94.6	99.3	112.4	125	138	
(G) Calculated Viscosity		84	94.7	105.4	116.1	126.9	138	

In each tube was placed 2 c.c. of mixture which contained 1 c.c. of an emulsion of washed ox corpuscles and 1 c.c. of isotonic gum solution and normal saline in various proportions.

Line/

Line (D) gives the estimated viscosities of the gum dilutions without corpuscles, and line (F) the readings given by the corpuscular mixtures. It will be noticed that these latter (F) rise fairly steadily as the quantity of gum increases.

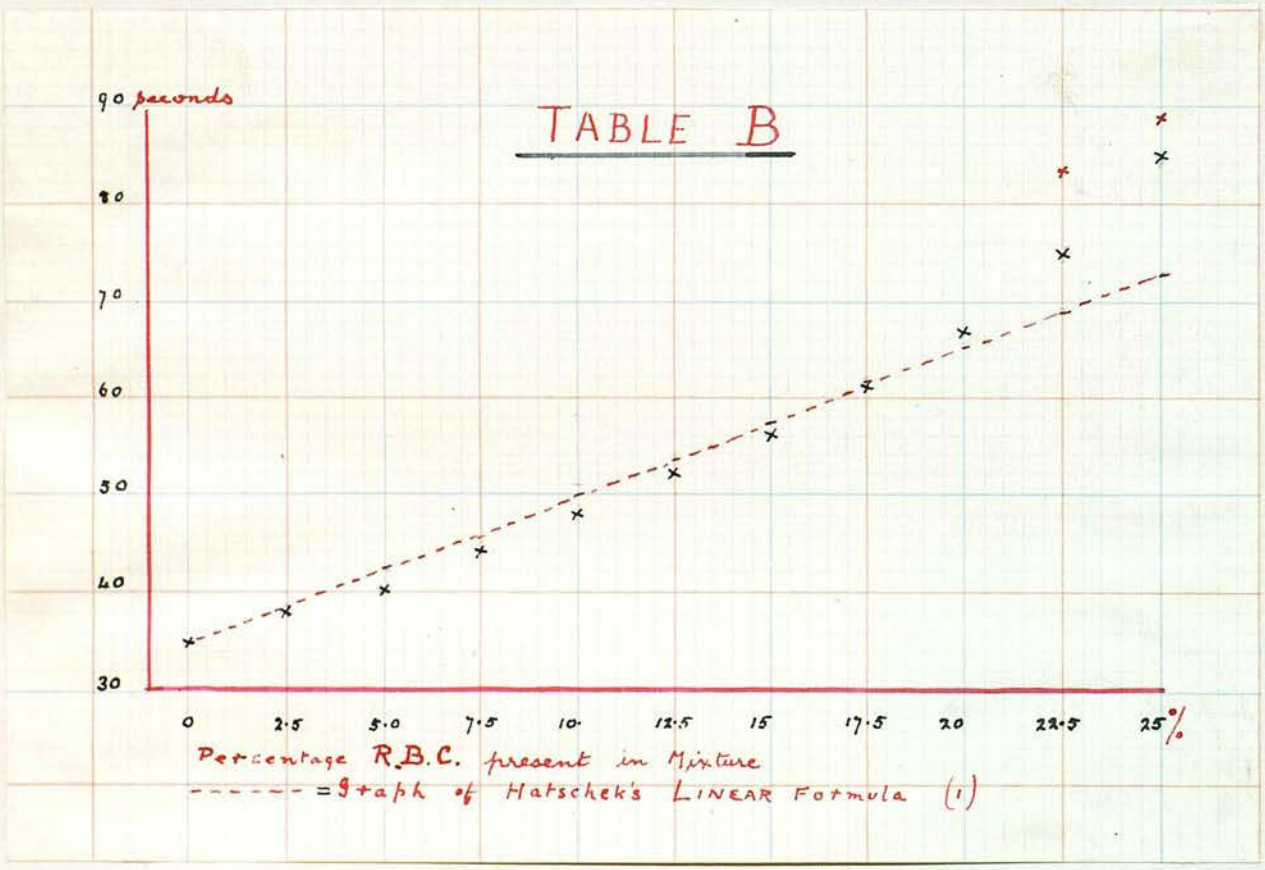
According to Hatschek's formulas the new viscosity V^o is formed from the original viscosity V multiplied by a factor $(1 + 4.5\ F)$ which deals with the corpuscular elements and of course in these experiments remains constant.

Hence V^o / V = a constant.

When the above table is examined it will be seen that the fraction 84/29 is much greater than 138/76 and the values of V^o / V fall steadily from 2.89 to 1.9. This apparent disagreement with the formula was explained when it was considered that the corpuscular emulsion contained, as well as corpuscles, a quantity of irremovable saline which would dilute the added gum mixtures. In the case of the weaker solutions the effect would be negligible, but it would be most marked where the gum was strongest. When allowance is made for this dilution the results calculated tally very closely with those observed. The sagging of the figures in tubes 4 and 5 is due to faulty mixing of the gum and saline, but the relation of the total viscosity to the "plasma" viscosity is normal.

This experiment was repeated on two other occasions/

TABLE B


90 seconds
80
70
60
50
40
30
0
2·5
5·0
7·5
10·
12·5
15
17·5
20
22·5
25%
Percentage R.B.C. present in Mixture
------ = Graph of Hatschek's LINEAR Formula (1)

occasions with different quantities of emulsion and a longer series of tubes, with the same satisfactory results.

When the figures found by experiment are corrected to allow for dilution by the saline present in the emulsion, the ratio V^o/V remains constant at 2.89. From this it follows that the viscosity of the plasma controls that of the whole blood. When the number (volume) of the corpuscles is constant the viscosity of the blood is a function of the plasma viscosity, increasing or decreasing in direct proportion with it. (The factor controlling this ratio $\frac{\text{Total } V^o}{\text{Plasma } V} = \text{Constant}$ is the corpuscular mass and varies with it, as we shall next see.)

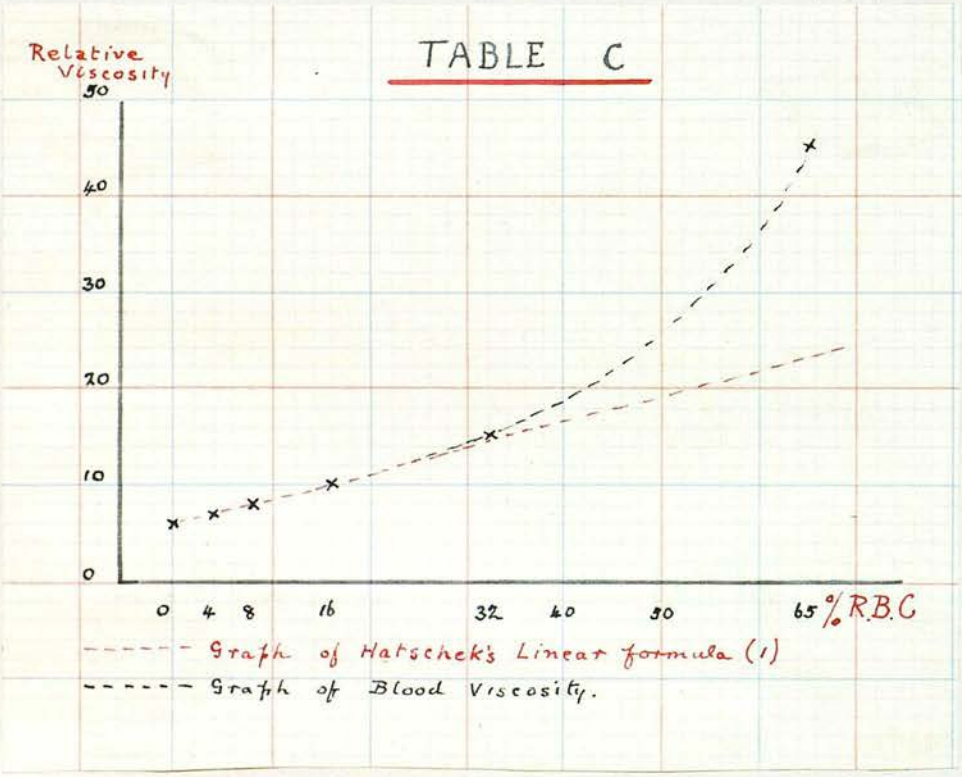
Influence of the Corpuscles on the Blood Viscosity.

TABLE B.

Tubes	1	2	3	4	5	6	7	8	9	10	11
A	(Saline)	2.5%	5	7.5	10	12.5	15	17.5	20	22.5	25% R.B.C
B	34.5	38	40	44	48	52	56	61	67	75	85
C	34.5	38.3	42.2	44.8	50.9	53.8	57.8	61.7	65.6	69.4	73.3
D										83.5	88.7

Mixtures were made of corpuscles in saline, the number of cells being varied. As the emulsion did not represent volume of R.B.C. it was necessary to estimate this by haematocrit or by calculation from the/

TABLE C


Relative Viscosity
50
40
30
20
10
0
0
4
8
16
32
40
50
65 % R.B.C
Graph of Hatschek's Linear formula (1)
Graph of Blood Viscosity.

the formula.-

$F = \frac{100\ V^{o} - 100\ V}{4.5\ V}$ an adaptation of Hatschek's.

Line "A" gives the percentage volume of cells present and line "B", the viscosity readings found. These rise practically steadily in a straight line until tube 10 is reached when the increase becomes more rapid.

The saline employed in the mixtures gave a reading of 34.5 and line "C" gives the figures based on this for the percentages of corpuscles present calculated from the formula $V^{o} = V\ (1 + 4.5\ F)$. They lie in a straight line and correspond closely with line "B" - the figures actually observed. The readings above 20% of R.B.C., however, are higher than the formula allows for.

The figures 75 and 85 would answer to a formula where Hatschek's constant 4.5 is replaced by .5 or 5.8.

Trevan's formula gives this constant as 6.3 and the results calculated by it - line "D" - are too high especially where the percentage of cells is small.

TABLE C.

Tube	1	2	3	4	5	6	
"A" (Saline only)		4%	8%	16%	32%	65%	R.B.C. calculated.
"B"	-	7	14	36	78	164%	Hb. estimated.
"C"	6	7	8	10	15.2	45.25	Viscosity.
"D"	6	7.08	8.16	10.32	14.64	44.94	

The/

The above table shews a similar series of mixtures containing a greater range of corpuscles.

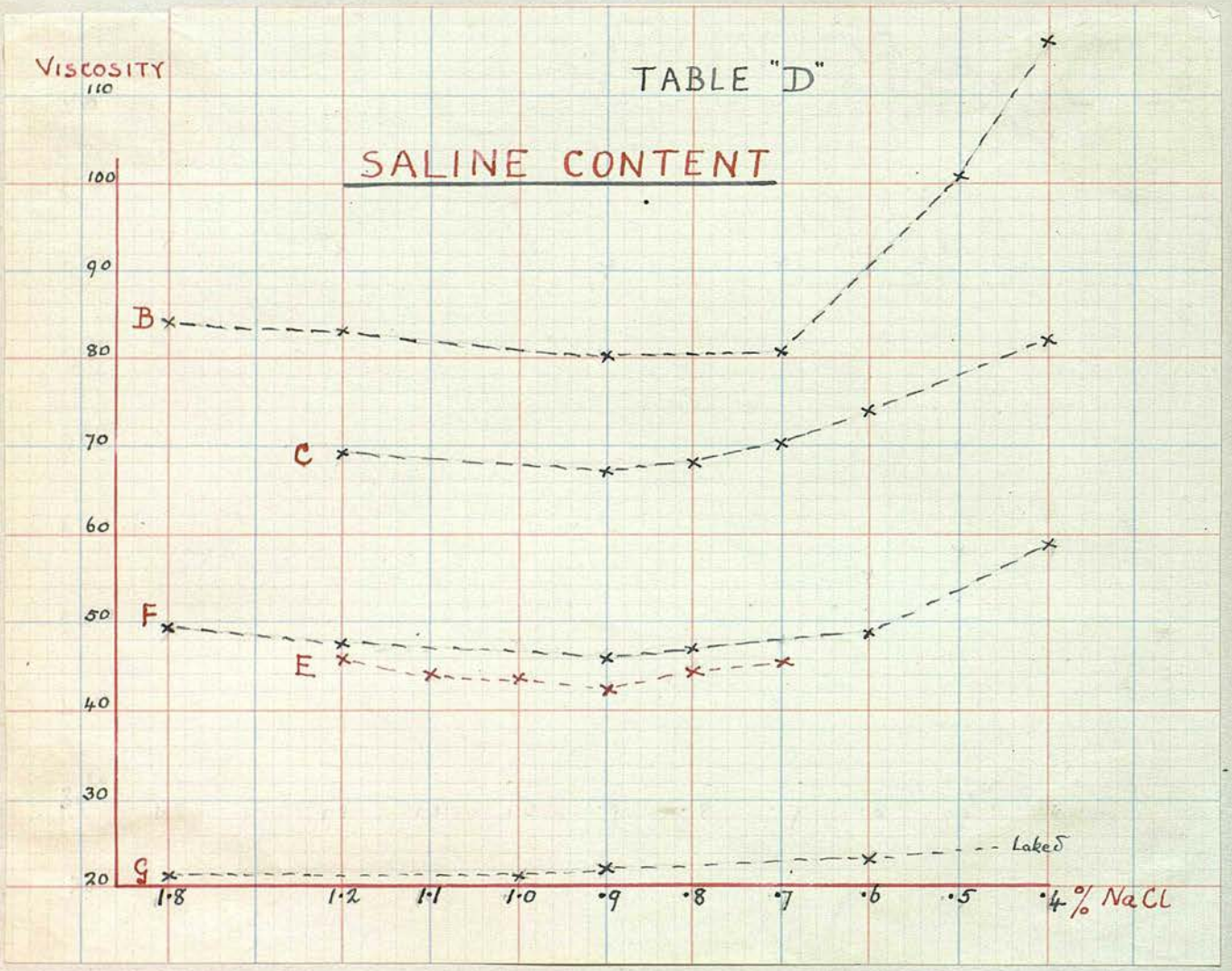
In the lower zone the figures mount regularly, but between the samples 5 and 6 a sudden rise takes place. A viscosity reading of 45.25 according to the inverted linear formula employed above, would correspond to a corpuscular percentage of 145.3 which is an impossibility. The viscosity figures calculated from Hatshek's formula, correspond very closely to my findings in the solutions containing below 32% of corpuscles.

When Hatschek's other formula $V^{o} = V \frac{\sqrt[3]{A}}{\sqrt[3]{A} - 1}$ is applied to tube number six, the figure obtained - 44.94 - closely approximates the actual finding, but applied to the volume of number 5 it gives 31.6, a viscosity reading much too high. Hatshek says this formula answers for systems where the solid phase is more than half the total volume, but Trevan believes it is useful as low down as 40%.

Seven other series of mixtures have been put up and investigated at various times. Different ranges of corpuscles have been employed and the fluid has been saline, plasma or gum solutions of different strength. All shew the applicability of these physical laws.

From these facts we conclude that with a constant plasma viscosity the corpuscles control the viscosity of/

of the whole blood . The increase or decrease of the viscosity in this case is not a simple linear ratio (as with the varying plasma) but becomes greater at higher concentrations. Up to about 20% of corpuscles the viscosity of figures follow practically a straight line according to Hatschek's first formula. Above 50% each increase of corpuscles leads to a very much greater viscosity increase which is expressed by Hatschek's second formula. Between these, the viscosity rises are greater than the linear formula allows and less than the other warrants, and must be met by an increasing value for the constant (4.5) of the first formula.


VISCOSITY
TABLE "D"
SALINE CONTENT
110
100
90
80
70
60
50
40
30
20
B
C
F
E
G
Lakes
1·8
1·2
1·1
1·0
·9
·8
·7
·6
·5
·4 % NaCl

The influence of the Saline content of the plasma on the Blood Viscosity.

This subject has received very little attention. Hirsch and Beck (1901) and Adam (1909) are the only authors who mention the question and point out that a change in the amount of salt present in the plasma may alter the total blood viscosity.

The red cells are extremely sensitive to alterations in the strength of the salt solution bathing them, swelling as the salts diminish and shrinking as they increase. It would be natural to think that the viscosity would change in similar fashion. Several series of experiments were performed to see if this was so.

TABLE D.

A	1.8%	1.2	1.1	1.0	.9	.8	.7	.6	.5	.4%
B	84	83	-	-	80	-	80.5	-	101	116
C	-	69.2	-	-	67.2	68	70	74	-	82
D	49	47.5	-	-	46	-	47.8	56	58	58.5
E	-	46	44	43.5	42.5	44.3	45.6	-	-	-
F	49.5	-	-	48	46.2	47	-	48.4	-	59
G	21	-	-	20.8	22	22.3	-	23	-	Laked.

Washed ox corpuscles were concentrated into a thick emulsion and were then mixed with samples of saline of different strengths. Line "A" gives the percentage/

percentage of salt present in the solution.
Line "G" contains the values obtained by Haematocrit for the corpuscles present in experiment "F".
In series "B" equal quantities of emulsion and saline were employed and in the remaining cases one part of emulsion to three of salt solution. The results seemed so unexpected and striking that the experiments were repeated with different samples on several occasions.

It will be noticed from the above table that any departure from the normal strength caused an increase in the blood viscosity. In the case of the weaker solutions this is easily understood, for the R.B.C. attempt to equalise osmotic pressure by imbibing fluid and rapidly swell at the expense of the plasma, which becomes correspondingly concentrated. The increased volume of the R.B.C. is shewn in the last experiment. (Line G) With further dilution the haemoglobin begins to be set free. The tubes to which .6% saline had been added shewed some degree of pinkness, and this was more marked in the .5% series. At .4% the mixtures were completely laked and clear.
Where the saline strength was above normal the solutions appeared unchanged to the naked eye, though microscopically, increasing crenation accompanied the addition of salt. Estimation of the volume of these mixtures confirmed this shrinkage and the relative increase/

increase of the plasma.

The increased volume of the plasma and its dilution by water abstracted from the corpuscles would tend to lower the viscosity of the mixture. That this does not occur, must be accounted for by the altered character of the walls of the corpuscles, the roughened surfaces adding greatly to the internal friction of the fluid.

To see if the change in the total viscosity could be the result of an increase of viscosity of the continuous phase, a series of mixtures was put up with strong gum and varying amounts of salt. The salt influenced the gum solutions only to a slight extent and that, not in a constant direction.

Mixtures of gum and salt.

Amount of gum constant - salt varied.

TABLE E.

Percentage of NaCl =	1.35%	.9	.78	.67	.56	.46
V. of gum mixture =	45.2	46	46.5	.46.5	46.25	46.

Mixtures were then made up of three parts of the gum and saline of above strengths and one part of corpuscular emulsion.

V. of R.B.C. gum mixtures	69.2	67.2	68	70	74	82

From/

From this it will be seen that the greatest influence of the salt is on the corpuscles, and that the blood viscosity is lowest when the plasma is isotonic with the corpuscles.

Effect of Haemolysis on Blood Viscosity.

The above experiments with mixtures of constant amounts of red corpuscles in varying strengths of saline, shew the effect of increasing haemolysis on the viscosity. In the .6% solution only a few corpuscles have broken down but their influence is at once felt; in the .4% tube all the corpuscles have been laked and the viscosity is greatly increased.

An interesting contrast between mixtures of R.B.C. in saline and in distilled water, is shewn in the following table.

TABLE F.

Proportion of emulsion to mixture.	Corpuscles counted.	V.of mixture in Saline.	V. of mixture in Water.
1 - 1	5170 000	2.8	6.75
1 - 2	2820 000	2.15	2.76
1 - 3	2410 000	1.60	1.87
1 - 4	1140 000	1.37	1.55
1 - 5	620 000	1.25	1.27
1 - 6	410 000	1.2	1.25

It/

It will be noticed that the laking increases the viscosity at all dilutions but that the effect is much more marked where the quantity of haemoglobin is greatest.

The effect of haemolysis is much better shewn when it is produced without dilution of the blood.

A sample of hirudinised blood, which had a viscosity of 6.85, was laked by rapidly freezing and thawing it, when the reading was found to have increased to 8.00. The increased viscosity remains after the corpuscular stromata have been removed by centrifugalisation, so that the effect must be due to the increase of protein (Hb) in the plasma.
Determann (1907) and Robert-Tissot have had opportunities of examining the blood in cases of Haemoglobinuria and have found the blood viscosity increased during the attacks.

Effect of Adding small quantities of Acid or Alkali to blood mixtures in vitro.

Minute quantities of N/100 HCl when added to blood samples made them so viscous that they could not run.

N/1000 acid was then tried. 0.1 c.c. of N/1000 acid in 2 c.c. of mixture produced no visible effect, the solution remaining quite red. 0.5 c.c. made the solution dark in colour and allowed slight diffusion of haemoglobin; with larger quantities the mixture became quite clear and then coagulation of the protein set in and produced a mass-like black treacle. During these changes the viscosity of the mixtures rose from 42.5 to 95.

A series of tubes was then set up with a smaller range of acid, as follows.-

		A	B	C	D	E.	F	G	H
R.B.C. Emulsion	cc.	.50	.50	.50	.50	.50	.50	.50	.50
.9% Saline	"	1.10	1.15	1.20	1.25	1.30	1.35	1.40	1.50
N/1000 HCl	"	.40	.35	.30	.25	.20	.15	.10	-
		Laked	-	Laking		Brown Red	-	Red	-
Flow time (seconds)		52.8	52.5	52.4	50.5	50	49	44	43

(The N/1000 Acid was made by diluting N/10 acid with normal saline so that the mixture might remain isotonic)

Increasing/

Increasing concentration of acid raises the viscosity of the mixture at first by producing swelling of the corpuscles and later by haemolysing them.

The blood mixtures were not nearly so sensitive to addition of alkali; relatively large amounts producing little alteration in the viscosity.

		A	B	C	D	E	F
R.B.C. Emulsion	cc.	.5	.5	.5	.5	.5	.5
.9 Saline		-	.5	.75	1.0	1.25	1.5
N/100 NaOH		1.5	1.0	.75	.5	.25	-
Flow time (seconds)		44	44	44	44.2	44	43.2

The presence of the alkali raises the blood viscosity to a slight extent, but the rise from .25 cc. to 1.5 cc. produces no further alteration of the figure.

Effect of various Salts on the Viscosity of the Blood.

As a rule the addition of a salt to a pure liquid, - water, - alcohol, - glycerine etc. - raises its viscosity to a degree proportional to the amount of salt present. In a few cases, however, the reverse occurs and the viscosity of the solution is less than that of the dissolving fluid. This "negative viscosity" is produced by the salts of a limited group of elements, - Rubidium, Caesium and Potassium (and occasionally by ammonium and sodium salts). The effect of the metallic radicle is most powerful in this order - Caesium, Rubidium, Potassium, and of the salts, - Iodide, Bromide, Chloride and Nitrate. All lessen the viscosity of water, of glycerine and of some mixtures of these and alcohol. The effects may vary at different concentrations, a positive viscosity being sometimes produced. A great deal of work on this subject has been done by Jones and his co-workers and has been published in the Carnegie Washington Institute monographs.

The most satisfactory explanation for this negative viscosity is that formulated by Veazey (1907).

When the molecular volume of the dissociated salt is smaller than the complexes of the solvent the viscosity of the system will be raised A negative viscosity appears as soon as the dissolved particles are larger than those of the continuous phase, since they/

they reduce the size of the total frictional surfaces. The elements mentioned are at the apex of the atomic curve.

The fact that potassium iodide could reduce the viscosity of water has been known for a long time, and many observers have sought to find if it could alter the viscosity of the blood too. The results have been most contradictory. Some authors state that they have succeeded in reducing the viscosity by the use of Pot. iodide, while others record that they could find absolutely no change even after prolonged administration of maximum doses. The question is one of very considerable interest from a clinical point of view, for, if Pot. iod. can lower the viscosity of the blood we have a weapon that will be of great use in certain cases, and this antiviscosing action may explain the benefit from the drug, seen in cases of high blood pressure and arterial disease.

A large number of experiments <u>in vitro</u> were carried out to see what the effect of iodine added to the blood was. Crystals added to blood, or to serum which was then mixed with the blood in various proportions usually raised the viscosity according to the amount of iodide present. When this was looked into it was found that it must be a hypertonic effect, the salt action of the iodide being added to that of the sodium chloride. Precautions were then taken/

taken to prepare solutions isotonic with the blood by making them the same fraction of a normal solution (N/65) that .9% saline is.
Solutions of 2.5% K.I. were diluted and a small quantity of blood was added to each. These mixtures were tested against similarly diluted .9% NaCl and haemolysis was observed at corresponding points. The isotonicity of the iodide solution was also confirmed by microscopic examination.

Effect of replacing NaCl by an equivalent of K.I.

		A	B	C	D	E	F
R.B.C. emulsion	cc.	.5	.5	.5	.5	.5	.5
0.9% NaCl	"	1.5	1.4	1.25	1.0	.5	-
25% K.I.	"	-	.1	.25	.5	1.0	1.5
Flow Time	Secs.	42.8	42	41.7	41.7	40.9	40.5

The above table shews that potassium iodide reduces the viscosity of blood *in vitro*, the results being proportional to the amount of the salt employed. The percentage of iodide in these experiments is, of course, relatively high.

Iodides are very rapidly eliminated from the body by the kidneys, and to obtain a reduction of blood viscosity *in vivo*, it would be necessary to employ large doses at frequent intervals. When working at absorption/

absorption from wound surfaces I found that the bulk of the iodide taken into the system appeared in the urine within the first hour or so. The iodide action on the blood would only be of short duration and would disappear as sodium chloride again replaced it in the fluid. This rapid disappearance may explain the failure of many observers to discover any reduction of viscosity under iodide medication.

Iodides were given to a number of my cases and after a time reduction of viscosity was quite frequently found, but as this usually coincided with a fall in the blood counts, it would be unfair to attribute it to the iodide.

Effect of Potassium Bromide on Blood Viscosity.

When Pot. Brom. was examined in the same way similar results were obtained. Hypertonic mixtures caused a large increase in the viscosity, isotonic mixtures a reduction. In this case however the changes were very slight, a flow time of 40.9 being only reduced to 39.44.

I also investigated the effect of Potassium Thiocyanate in the same way, and found it produced some reduction of viscosity. Pauli (1903), who emphasises the close similarity of this drug to potassium iodide and bromide both in its chemical and/

and pharmacological actions, enthusiastically claims for it a powerful antiviscosing effect.

Of other salts tested by replacing them for sodium chloride in isotonic solution, the following produced no effect on the blood viscosity - sodium bicarbonate, sodium fluoride and potassium nitrate.

Others again caused a slight but definite increase in the flow time.- potassium chloride and chlorate, sodium carbonate and phosphate, for example -

R.B.C. emulsion	cc.	.5	.5	.5	.5
0.9% NaCl	"	1.5	1.0	.5	-
2.3% Na_2HPO_4	"	-	.5	1.0	1.5
Flow time.	Secs.	45	46.6	47.7	48.3

Records of Clinical Cases collected under Diseases.

Having analysed the factors which influence the viscosity of the blood, we are now in a position to examine the findings in clinical cases. The blood has been investigated in a large number of diseases and some of the more interesting results are presented in the following pages. To facilitate examination, data from all the cases were tabulated under the heading of different diseases, and some of the tables are included below.

Certain diseases are constantly associated with more or less profound changes in the blood and in these we would expect to find the blood viscosity also affected, but modifications of the viscosity occur in many other conditions as well.

Blood Viscosity in Cases of Anaemia.

In our clinical analysis we have already shewn the great importance of the red blood corpuscles in controlling the viscosity, and from our laboratory experiments we found that the viscosity follows the number of the red corpuscles according to definite physical laws, when the quality of the plasma remains constant. This being so, we would expect to find that the viscosity changes in anaemia cases, were directly proportional to the loss of corpuscles. For the most part this is the case, but in vivo the conditions are not so simple as in laboratory experiments and many discrepancies occur. If the red corpuscles were the principal factor in the maintenance of the blood viscosity it would be easy to tell the viscosity from the number of erythrocytes found. Experience, however, shews that no such rule is applicable,and a blood count can not be considered a substitute for a viscosity estimation. The explanation lies in the fact that the composition of the plasma also varies in different degrees and different varieties of anaemia.

The symptoms of anaemias are usually attributed simply to the diminution of the red cells, but it is probable that many of them owe their existence to the reduced viscosity which the poverty of cells produces.

We/

We have already seen that in anaemic subjects a low viscosity is associated with a low blood pressure, which is not entirely due to weakness of the cardiac pump.

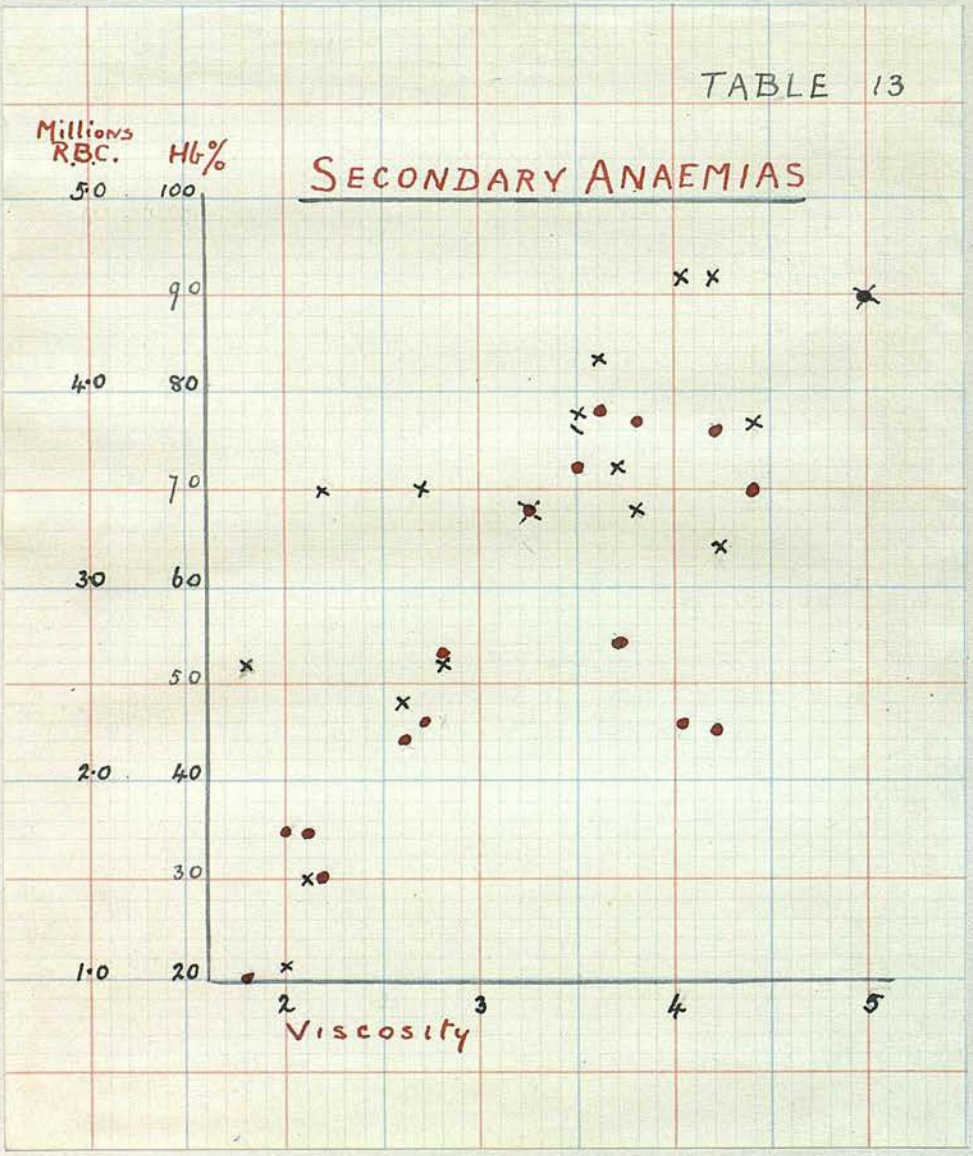
The rapid pulse found in such cases is an attempt by the heart to compensate for this deficient blood pressure.

In a pulsating stream like the human circulation, it is not the maximum systolic pressure which is the measure of efficiency, but the "mean pressure" during the pulse cycle. If the trough between the waves be allowed to fall too far, the mean pressure falls with it to an abnormal degree. Increased heart rate remedies this by approximating the crests of the waves, so that the new upstroke is begun before the trough has become too low. From this it follows that the character of the pulse also, depends largely on the viscosity of the blood.

Palpitation, a common complaint of anaemic cases, may also arise from the thinness of the blood. The normal blood offers a certain resistance to the contracting heart and steadies its contraction. When the blood viscosity is low this resistance is reduced and with it the steadying action disappears. This can readily be appreciated when studying the effects of altering the (peripheral) resistance in an artificial circulation actuated by a Higginson syringe.

It may be that the haemic murmurs characteristic of these diseases, depend partly at least, on the alteration from a steady silent stream to turbulent flow such as occurs in fluids when the "critical speed of Reynolds" is overpassed. Reynolds in his paper (page 937) notes that the less viscous a fluid is, the more prone it is to eddying or sinuous motion.

TABLE 13


Millions R.B.C.
Hb%
SECONDARY ANAEMIAS
5·0
4·0
3·0
2·0
1·0
100
90
80
70
60
50
40
30
20
2
3
4
5
Viscosity

Conditions shewing Anaemia of varying degree.

TABLE 13.

Case	Sex.	Age.	Viscosity.	R.B.C.	Hb.	W.B.C.	Remarks.
311	F.	38	1.82	2610000	20	7700	Secondary Haemorrhage.
499	F.	23	(2.00	1060000	35	7200	Anaemia of pregnancy (7th Month)
			) (2.30	1540000	35	29200	1 day after induction of Labour.
481	F.	67	2.30	3510000	30	6800	Sarcoma of duodenum.
507	F.	53	2.75	2400000	44	6200	Haematemesis.
238	M.	11	(2.75	3510000	46	17000	Haemophilia after 19 days bleeding.
			) (2.75	2600000	53	11200	" 3 weeks later.
489	F.	33	2.87	-	-	-	Puerperal Thrombosis in Varicose vein
70	F.	34	3.50	3840000	72	-	Puerperal Anaemia ($\overline{c}$ white leg)
133	F.	40	(3.65	4350000	78	7800	Severe Menorrhagia. (3 weeks)
			) (3.30	3450000	68	10400	" "
339	F.	44	3.75	3620000	54	4400	Anaemia and displaced Kidney.
251	F.	44	3.82	3490000	77	-	Tonsillitis and Graves' disease.
341	F.	22	4.05	4650000	46	9000	Phthisis (T. 101.6°)
465	F.	38	4.22	4610000	76	8100	Haematuria for 2 months.
439	M.	29	4.25	3240000	45	7600	Scurvy and Anaemia.
237	F.	$4\frac{1}{2}$	4.48	3780000	70	22000	Purpura.
118	M.	32	5.12	4510000	90	5800	Purpura haemorrhagica (Conval.)
521	M.	11	5.2	-	-	-	Purpura, Herpes, etc.

Secondary Anaemias.

The effect of a rapid loss of blood has already been shewn under the heading of "venesection".

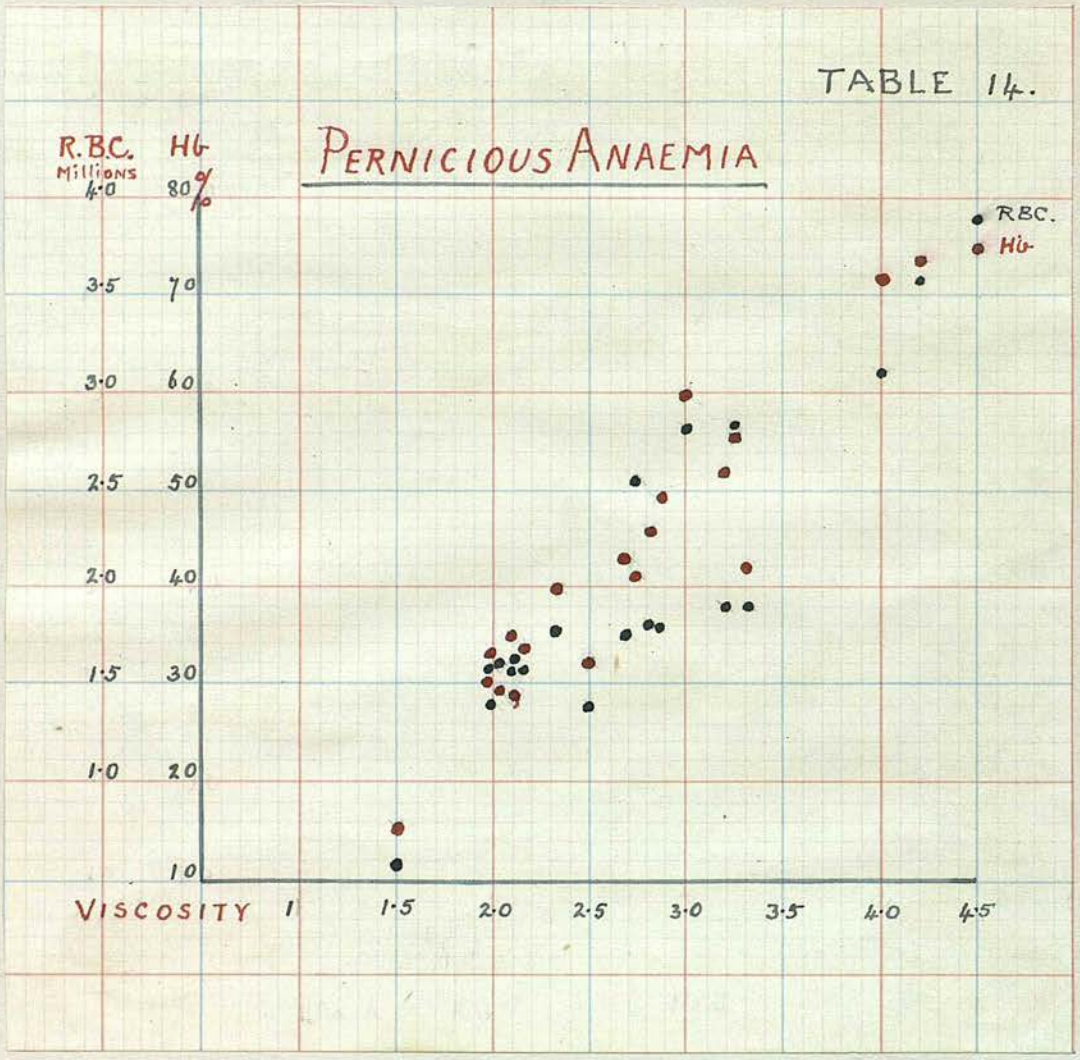
On the accompanying table are collected a number of cases shewing various degrees of anaemia. They cover a fairly wide range of conditions from a large haemorrhage to the anaemia of tuberculosis. It will be seen from the table that the figures in the columns for viscosity, red corpuscles and for haemoglobin time mount together in fairly steady fashion, but every here and there an unexpected result is got. This may be explained by the rapidity with which the loss of blood has taken place. Where a large haemorrhage has occurred the bulk of the blood is at once made up by addition of water to it, so diluting the remaining fluid, but where the anaemia is more gradually produced, this thinning of the plasma is less likely to occur.

The most severe cases head the list, while at the foot of it are some convalescents with normal figures.

The number of white cells appears to have no influence on the viscosity of the blood.

A number of cases shewing thrombosis in veins or embolism following thrombosis, gave figures which seemed to correspond closely with the blood counts found in them.

TABLE 14.


PERNICIOUS ANAEMIA
R.B.C. Millions
Hb %
4·0
3·5
3·0
2·5
2·0
1·5
1·0
80
70
60
50
40
30
20
10
RBC.
Hb.
VISCOSITY 1
1·5
2·0
2·5
3·0
3·5
4·0
4·5

Pernicious Anaemia.

TABLE 14.

Case	Sex	Age	Viscosity	R.B.C.	Hb.	W.B.C.	Remarks.
525	F.	29	1.50	560,000	15	-	Blood just like plasma.
121	M.	50	(2.25	1640000	34	2600	2 Aug.
			(2.35	1720000	40	2500	13 Aug.
64	M.	30	2.70	1750000	43	2100	
412	M.	59	(2.72	2600000	41	7400	5 March.
			(2.75	2350000	28	13800	15 March. Delirious.
36	F.	-	3.65	2760000	62	-	
449	F.	36	2.05	1390000	30	3700	17 April.
			2.05	1600000	29	4300	22 April. Liq.Ars.mx t.i.d.
			2.07	1580000	29	4400	24 April.
			3.00	2850000	60	5900	14 May.
			3.05	3700000	68	6500	28 May. Arsenic stopped 26th May.

302. M. Had Pernicious anaemia from March - May but recovered sufficiently to work all summer. Felt ill 14 days before admission on Nov.3rd but worked till two days ago. Very dyspnoeic, feet swollen.

3rd Nov.	2.2	1480000	32	2800	Liq. Ars. mx t.i.d.
9th Nov.	2.2	1610000	35	4600	
14 Nov.	2.50	1450000	36	3600	
28 Nov.	3.35	1850000	42	4000	Liq.Ars. mxv. t.i.d & Virol.
5 Jan.	4.03	-	-	-	
10 Jan.	4.25	-	-	-	

In Case 273 a male aged 26 - the illness first began 18 months before present examination. Patient recovered for a time but turned ill again 4 months ago, since when he has been unable to work.

Date	Viscosity	R.B.C.	Hb.	W.B.C.	Remarks.
22 Sept.	3.2	1900000	52	3600	Liq.Arsenic mxv t.i.d.
13 Oct.	3.25	2750000	56	3100	Arsenic stopped to-day.
6 Nov.	2.75	1810000	46	4200	Pot.Bic.gr.xx t.i.d. and Sanatogen.
11 Nov.	2.74	1780000	50	3700	Not so well, Morning sickness.

Case 348, a male aged 20, had been treated for Pernicious Anaemia six months previously. He had recovered sufficiently to return to work and remained well until 14 days before admission on Jan. 29th. He now complains of weakness and diarrhoea.

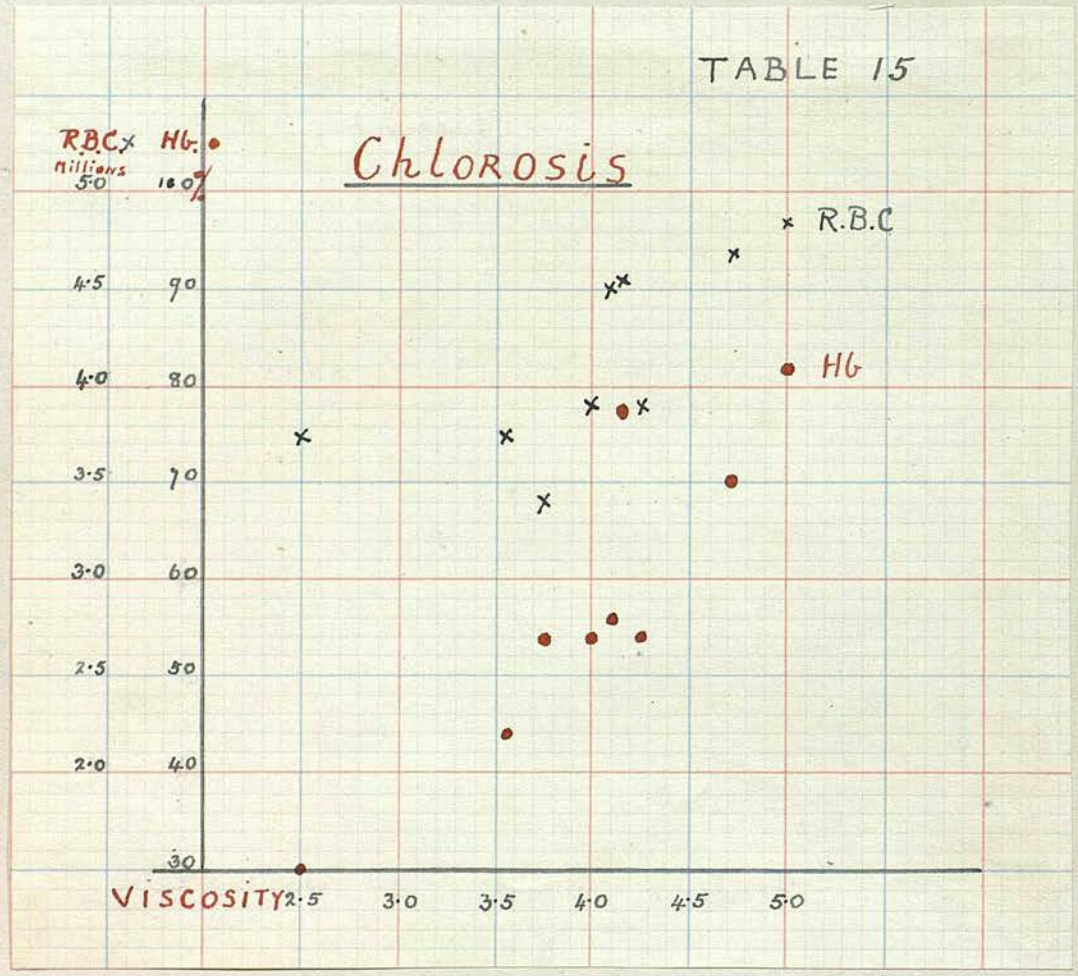
Date	Viscosity.	R.B.C.	Hb.	W.B.C.	
30 Jan.	4.5	3880000	76	2200	Having Bism. Salicylate gr. xv.
8 Feb.	4.25	3650000	74	4200	
19 Feb.	4.00	3150000	72	6000	

The viscosity figures in some of the pernicious anaemias shewn above, are very low and seem to correspond fairly well with the blood findings. When examined more closely and compared with the cases/

cases of secondary anaemia, it will be observed that the viscosity is really higher than would be expected from the red blood cell count. This depends on the relatively higher amount of haemoglobin present in this series. The colour index, worked out for this group of cases, shews absolutely no relation to the viscosity figures.

Several of the cases have been followed over a considerable period of time, and in these the blood viscosity is found to vary fairly closely with red cells, and their haemoglobin. Numbers 449 and 302 shew a steady rise in all the figures as the condition improves under arsenic administration. In the other two cases (Nos. 273 and 348) the figures fall as the patients gradually go down hill.

TABLE 15


Chlorosis
RBC × Millions
Hb •
%
5·0
4·5
4·0
3·5
3·0
2·5
2·0
100
90
80
70
60
50
40
30
R.B.C
Hb
VISCOSITY
2·5
3·0
3·5
4·0
4·5
5·0

Chlorosis Cases.

TABLE 15.

Case	Sex	Age	Viscosity.	R.B.C.	Hb.	W.B.C.	Remarks.
310	F.	19	2.50	3740000	30	4500	
347	F.	16	3.55	3750000	44	8100	7 Feb. Been having salicylates.
			4.00	3900000	54	7200	19 Feb. On Iron Jelloids.
			4.10	4580000	56	8900	13 March. Greatly improved
387	F.	23	3.75	3400000	54	2600	
304	F.	25	4.25	3910000	54	6700	
245	F.	19	4.17	4560000	78	8400	Convalescent, (very Constipated)
103	F.	21	4.70	4680000	70	9100	Convalescent.
104	F.	24	5.00	4780000	82	4800	Convalescent.

The accompanying table contains both mild and severe examples of the disease as well as some convalescents.

The haemoglobin figures cover a wide range, though the red corpuscles are not so low as in the previous tables.

The viscosity readings, too, are on a correspondingly higher plane, but the difference between the extremes - 5.00 and 2.50 - is much greater than is

to/

to be expected from the R.B.C. figures, 4,780,000 and 3,740,000. This contrast is readily explained by the haemoglobin figures - 82% and 30%. From this it would seem that in chlorosis the percentage of haemoglobin is of greater importance for the blood viscosity than the number of the red cells is. The same is also true of pernicious anaemia.

Number 347 illustrates the beneficial effect of administration of iron in such cases.

An interesting comparison of the three types of anaemia is got when a composite table is made shewing the R.B.C., and Hb. figures which correspond to the same viscosity.

It is noteworthy that whereas the secondary anaemia cases are distributed uniformly from 1.8 up to normal figures, the bulk of the pernicious anaemias have viscosities under 3 and the majority of the chlorosis cases lie above this figure.

In secondary anaemias the number of the red cells and the percentage of haemoglobin tend to maintain their normal ratio (i.e. the C.I. is not far from 1.) while in chlorosis and in pernicious anaemia these figures vary in opposite directions (low or high C.I.)

Thus/

Thus a viscosity reading of 2.4 would be given by a secondary anaemia with 2500000 R.B.C. and 40% Hb,
a pernicious case " 1400000 and 36
and a chlorosis " 3700000 and 30

Similarly a viscosity of 4 is shewn by
a secondary anaemia of 4600000 R.B.C. and 46% Hb.
a pernicious " " 3100000 and 72
and a chlorosis " 3900000 and 54.

Blood Viscosity in Cardiac Cases.

If a cardiac lesion, however severe, is well compensated for there is no reason why the blood viscosity should be other than normal. When compensation fails, as it has in many heart cases who seek medical advice, conditions are quite altered. The object of the heart is to maintain an efficient circulation of the blood. The essential part of the circulation is the capillary areas where the blood is brought in close contact with the organs and tissues of the body, giving up a certain amount of oxygen and nutrient substances to them and taking away CO_2 and other waste products. In health the blood does not give off all its oxygen to the tissues nor does it become saturated with CO_2. The first result of a failing heart is a slowing of the blood stream, which shews itself most in the smallest blood channels. The blood fluid now remains longer in contact with the tissues and in consequence loses a greater amount of its oxygen, at the same time taking up more CO_2. This anoxaemia produces the condition of cyanosis. We have already seen that an addition to the CO_2 content of the blood, very markedly increases the viscosity of the fluid.

Here, then, we have a serious vicious cycle, as was first pointed out by Koryani (1906), - a poorly acting/

acting heart allows an accumulation of carbon dioxide in the blood, and this by exaggerating the viscosity throws still more work on the heart. Koryani also emphasised the great benefit to be derived from oxygen inhalation in such cases.

Where the cardiac lesion is of such a nature that the heart cannot fully compensate for it by hypertrophy or increased activity, the body tries to assist by increasing the number of the red cells in the blood. This polycythaemia is a common feature of mitral stenosis cases and where congenital heart lesions are present. There is a limit to the usefulness of this cellular increase, for a point is soon reached at which further increase unduly raises the blood viscosity and so embarrasses the already damaged heart. It will be remembered that blood viscosity increases in linear ratio with each addition to the corpuscular volume till it reaches about 40%, (this corresponds to about 5,000,000 cells per c.m.m.). Above this level further additions produce a disproportionately great augmentation of the viscosity. From this it follows that the normal number of blood cells is the most economical that the body can work with. In spite of this the number of red corpuscles may far exceed the normal. Cases of <u>polycythaemia</u> have been described where the high level of 11,000,000 was attained.

Hutchinson/

Hutchinson and Miller (1906)[X] described such a case where the viscosity of the citrated blood was 11.8 times that of water. Parkes Weber and Dorner (1911)[*] had a case of congenital heart disease where the polycythaemia amounted to 10,100,000 and the viscosity rose to 35.9.

A number of my heart cases show a considerable increase in the erythrocyte count, but the highest was given by a boy of 15 with a congenital pulmonary stenosis, and very marked cyanosis. The red cells numbered 9,810,000 and the haemoglobin 140%, while the viscosity amounted to 24.25, nearly five times the normal figure.

Another accompaniment of failing hearts is "cardiac oedema" and cases where this is present may shew a lower viscosity than those without it. This oedema is usually looked upon merely as an accumulation of a watery fluid in the tissues, but the diminished viscosity in these cases and the improvement that accompanies the use of diuretics and digitalis suggests that the blood itself is hydraemic. Similar findings are reported by Austrian (1911), Martinet (1912), Parturier and Dons Kaufmann (1917).

This/

X Hutchinson and Miller 1906 Lancet, p.744.

* Parkes Weber and Dorner 1911 Lancet, p.150.

This dilution of the blood and the reduction in blood viscosity that it produces would tend to counteract the viscosing effects of carbon dioxide, and may be looked upon as a salutory mechanism. Hess (1904) says that in decompensated heart cases the blood may be either thicker or thinner than normal, the dilution being due to the tissues giving up more fluid because of the diminished pressure. This would hardly explain the accompanying oedema, however.

Von Noorden[+], summing up the findings of Grawitz[‡] and of Askanazy[‡] states that.- "(1) when the compensation is good the composition of the blood remains normal; (2) when compensation fails, and particularly in the early stages of its failure, the blood becomes more dilute; it may either remain dilute, return to normal, or even become abnormally concentrated as the case progresses."

Some heart cases shew a certain amount of anaemia which tends to keep the viscosity reading down.

The most normal results are found in simple aortic cases, either stenosis or incompetence, and in well compensated mitral escape. On the other hand, mitral stenosis cases, except the very mildest ones, always shew some increase in the blood viscosity and a high blood count. The longest readings are got in cases of heart failure where cyanosis is present but no oedema.

+ v. Noorden 1907 Metalolism & Practical Medicine, Vol. 2, p. 335.
‡ Grawitz 1902 Klin. Path. des Blutes, p.491.
‡ Askanazy 1897 Deutsch.Arch.f.kl.Med.(59) p.385.

Mitral Stenosis.

TABLE 16.

Case	Sex	Age	V.	R.B.C.	Hb.	B.P.	Oedema	Cyanosis	Dyspnoea	Onset.	
423	M.	32	(4.00)	4070000	62	106	Nil	Nil	-	6 yrs.	(3 April)
			(4.12	-	-	108	Nil	Nil	Slight	Readmitted	(10 June)
			Now has slight pleural effusion.								
430	F.	19	5.30	5260000	98	95	-	-	+	Sudden breathlessness and haemopthysis (pulm. infarction) on previous day.	
309	M.	28	5.95	5320000	96		++	+++	+	3 weeks ill.	(7 Nov.)
			Has had Asthma, Bronchitis and emphysema for years.								
			6.25	5170000	100	110	+++	+++	++	Southey's tubes in legs.	(9 Nov.)
			Died suddenly on 12th Nov.								
485	M.	24	6.10	5100000	92	110	Nil	++	Nil	1 week.	(30 May)
			6.00	5020000	100	126	Nil	+	Considerably improved.		(11 June)
86	M.	22	6.40	5570000	106	105	Nil	+++	+	Years.	(29 June)
			Heart trouble for many years - extremely cyanosed.								
			5.42	5440000	104	108	Nil	+	-	Greatly improved.	(2 Aug.)
			4.70	5060000	100	100	Nil	+	-	Going about now.	(14 Aug.)

Case 424. A Male patient aged 21. History of heart lesion for six years. Unable to work for 18 months. Developed a cough a month ago and became rapidly worse after that. 4 days ago legs began to swell.

	R.B.C.	Hb.	Oedema	Cyanosis.	Dyspnoea.	
V = 11.00	7520000	112	- slight	+++	++	(3 April)
	Strophanthus causing vomiting - unable to retain any food all day.					
V = 5.45	5170000	110	- Nil	+	+	(17 April)
	Dulness at L. Base.					
V = 4.70	4450000	88	- Nil	+	+	(28 May)
	Been up for some days.					
V = 4.57	4120000	80	- Nil	-	-	(10 June)
	Much improved.					

Mitral Stenosis.

The example heading the table (Case No.423) is a mild case shewing no heart symptoms, but some anaemia which accounts for the reduced viscosity readings.

In all the other cases the viscosity figures are distinctly high and some polycythaemia is present. Varying degrees of cyanosis and dyspnoea are shewn but oedema is only marked in one case (No.309) which in consequence occupies a place high in the list. His condition rapidly got worse, oedema, dyspnoea and blood viscosity increased and he died a few days later.

The remaining cases shew the changes that accompany the administration of cardiac tonics. As the symptoms disappear the blood counts fall, and with them the viscosity figures which may even come to be below the normal. In these cases the polycythaemia only persists so long as it is acually needed.

Mitral Incompetence.

TABLE 17.

Case	Sex	Age	V.	R.B.C.	Hb.	B.P.	Oedema	Cyanosis	Dyspnoea	
452	M.	50	4.25	4410000	82	184 S	Gone	-	-	Getting up now.
178	A boy of 12 years, convalescent from an attack of rheumatic fever which had affected his mitral valve,									
			4.70	4520000	89	105	Perspiring freely	-	5.20 p.m.	23 Aug.
			4.60	4580000	89	107			3 p.m.	28 Aug.
			4.55	4540000	90	105			10.50 a.m.	2 Sept.
			4.65	-	-	104			10.30 a.m.	5 Sept.
			4.50	-	-	102			12.10 p.m.	5 Sept.
			4.62	-	-	110			2.30 p.m.	5 Sept.
							Rather heated after exerting himself at bowls.			
			4.70			107			4.5 p.m.	5 Sept.
321	F.	34	8.50	5440000	102	160	+++	+++	+++	14 Nov.

Case/

Case admitted 7th September, - very oedematous and cyanosed, has not improved in spite of treatment with expectorants, diuretics and digitalis. Still passing very little urine (8 - 10 ozs.) which contains .2 grs. albumin. Has been on a salt free diet for four days, but remains extremely oedematous and cyanosed.

Mitral Incompetence.

The three cases shewn under this heading offer a sharp contrast to each other.
No.178 was a boy who had just had his first attack of rheumatic fever. His heart was not seriously affected and no change in the blood was to be expected. The viscosity readings simply shew the daily variation.
No.452 was an old heart case recovering from an attack of heart failure, while the remaining case shews extreme degrees of dyspnoea, cyanosis and oedema.

AORTIC LESIONS.

Stenosis of Aortic Valve. TABLE 18.

Case	Sex	Age	Viscosity	R.B.C.	Hb.	B.P.	Oedema	Cyanosis	Dyspnoea.	
454	M.	62	4.25	4760000	75	180 S	+	—	—	
308	M.	25	4.95	5490000	95	-	Nil	Nil	Nil.	Very marked

Stenosis of aortic valve, Rheumatic fever 2 years ago, Heart attack 1 year ago. For 3 weeks now has complained of severe cough and pain.

142	M.	35	5.20	4890000	90	132 P.	Nil	Nil	Nil.	Occasional

attacks of dyspnoea for 20 years, for which he has frequently been treated in hospital. Now convalexcing after 3 weeks in the Infirmary.

The first Case (No.454) has a rather low viscosity reading which is readily accounted for by the poor haemoglobin figure.
The other cases shew practically normal counts though the conditions are very marked and of long standing.

Aortic Stenosis and Incompetence.

TABLE 19.

Case	Sex	Age	Viscosity	R.B.C.	Hb.	B.P.	Oedema	Cyanosis	Dyspnoea	
426	M.	57	5.37	5160000	89	-	Nil	+++	+	Off work for 2 mths.

Case 307. A man aged 61, with a well marked double aortic lesion, had a sudden attack of haemoptysis the day before examination. Crepitations at both bases, much frothy sputum.

5.50	4990000	90	145 S.	-	-	+	(6 Nov.)
4.98	5040000	90	140 S.	-	-	-	(9 Nov.)
5.10	4780000	90	140 S	Now aphasia and has L. arm paralysed.			(14 Nov.)

Case 431. A male aged 28, - well until beginning of Oct. On Oct. 11th developed pleurisy and lobar pneumonia. Made a good recovery and was going about in the ward when he began to complain of shortness of breath. Aortic bruits were first detected on Nov. 12. Dyspnoea on exertion increased during winter and patient was unable to work. On March 15 he took a cold and became more dyspnoeic than ever. When admitted to hospital 3 weeks later he had some shortness of breath, no oedema, but was slightly/

slightly cyanosed.

V.	R.B.C.	Hb.	B.P.	Oedema	Cyanosis	Dyspnoea.		
5.75	4730000	96	155	Nil	+	++	Urine 24 ozs.	(8 April)
5.85	-	-	-	Nil	+	++	Urine 52 ozs.	(22 April)

Now developed slight pericarditis.

The first two cases shew readings a little higher than the normal for their ages, the third case is probably a mild ulcerative endocarditis and shews a fairly high viscosity figure. He was not running a temperature at the time of examination.

Combined Aortic and Mitral Lesions.

Case 301. A man of 41 years, began to have attacks of anginous pains 3 years ago. Legs began to swell first in February, but he carried on work until August, when dyspnoea, sleeplessness and vomiting became prominent.

Examined on 25th October, - shewed well marked double bruits in all areas. Now passing 80 ozs. urine in 24 hours. It contains blood and granular casts and .87 grs. of albumin per oz. The legs and trunk are waterlogged and there is a great deal of fluid in the peritoneal sac.

(25 Oct.)

V.	R.B.C.	Hb.	B.P.	Oedema	Cyanosis	Dyspnoea.
3.45	3450000	65	145 P.	+++	-	+

Treated with Digitalis and diuretics.

Frequent epistaxis.

(14 Nov.)

3.70	3120000	62	140 P.	+++	-	+

Urine has now fallen to 12 ozs. and contains blood and albumin .2 grs. He is being dry cupped daily. Patient died on Nov. 19th.

Case	Sex	Age	V.	R.B.C.	Hb.	BP.	O.	C.	D.	
484	M.	26	4.50	5000000	82	130	?	+	-	5 weeks.

Heart attacks for 9 years. Aortic and Mitral stenosis.

107	M.	19	4.62	4850000	82	120	+	-	+	

Few months history Aortic and Mitral incompetence, urine from 16 - 48 ozs. daily.

Case 88. A man of 51, had rheumatic fever 13 years ago but remained well until 18 months ago. Since when he has had several heart attacks. Blood first examined at Convalescent House after patient had been one month in hospital Double bruits present in all areas, the urine contained small trace of albumin, but there was no dyspnoea nor oedema.

30 June	-	4.75	4590000	70	160 P.	-	-	-	

About a week later legs began to swell and he complained of abdominal pains. He was then returned to hospital.

3 Aug.		4.50	5200000	94	168 P.	+			

Oedema of legs. (passing 38 ozs. urine)

1 Sept.		4.76	4520000	94	165 P.				

Oedema gone, passing 80 ozs. urine daily.

9 Oct. Died. At P.M. found congenital cystic kidneys in addition to cardiac lesions.

Case 433./

433. A youth of 19, had a very rheumatic history for many years and had never enjoyed good health. For the past 3 months had been short of breath. On admission was very cyanosed and had some slight oedema of legs. There was evidence of aortic and mitral stenosis and mitral and tricuspid incompetence. Urine 32 ozs. per diem, contained many casts and albumin 1.5 gr. per oz.

	V.	R.B.C.	Hb.	B.P.	O.	C.	D.
10 April	5.05	4700000	80	156 S.	+	++	+
16 April	6.07	-	-	130 S.	Oedema much less, other symptoms improved. Higher reading probably due to action of diuretin and strong saline purgative.		

The above cases shewing combined aortic and mitral lesions require little comment, the opposing actions of increased carbon dioxide and hydraemia are sufficiently obvious.

In No. 301, where the patient is going rapidly down hill, it will be noticed that the viscosity rises though the blood counts are going down. The same thing is seen in the last two examinations in number 88.

Non Valvular Cardiac Cases.

TABLE 20.

Case	Sex	Age	V.	R.B.C.	Hb.	B.P.	Oedema	Cyanosis	Dyspnoea	Remarks.
200	F	36	4.28	4710000	82	102	-	-	-	General and Cardiac asthenia, (ovaries removed 3 years ago.)
377	M	72	4.55	3750000	80	168	Calcified arteries. Chronic cough for years. Present attack - dyspnoea and oedema, with dilatation of right side of heart. Both dyspnoea and oedema disappeared when he was put in bed.			
260	M	79	4.70	4800000	86	148 S.	++	-	++	Chronic Bronchitis for years, worse for last few months. Dyspnoea, palpitation and sleeplessness. Swelling of feet for last 14 days. Urine scanty, contains trace of albumin and few casts.
233	M	39	4.95	4730000	87	118	-	-	-	Convalescent. Cardiac Asthenia.
340	M	58	5.82	5200000	80	178	++	+	+	Cardiac dilatation in case of chronic Nephritis (alb. 1.8 gr. per oz) Died 3 weeks later.
22	M	53	5.87	4940000	100	1155	-	-	-	Chronic Bronchitis with myocarditis and arrhythmia.

Cases of myocarditis or cardiac weakness without definite organic valvular lesions shew changes similar to those in other cardiac cases. In this series cyanosis was not very obvious, while oedema was fairly frequent. Only the last two cases in the list shew high viscosity readings, while all the others are somewhat low and have correspondingly reduced blood counts.

A wide range of blood pressure readings is presented, the two lowest in asthenics of middle age, the highest in patients where obvious arterial and renal disease co-existed.

Acute and Chronic pericarditis cases are classified with rheumatic fever in the course of which most of them occurred.

Arterio-Sclerosis Cases.

TABLE 21.

Case	Sex	Age	V.	R.B.C.	Hb.	B.P.	Vessel.	Remarks.	
839	M.	61	4.75	4720000	89	200	+++	Fibrositis (Convalescent)	9th Sept.
			5.10	4990000	91	198			18 Sept.
			5.30	4930000	91	210			20 Sept.
8	F.	23	4.92	5010000	85	220	+++	Renal Cirrhosis (Conval.)	5 June.
			4.95	4800000	88	220		"	15 June
80	M.	56	5.20	4420000	85	165	++	A Hospital "chronic" now. Convalescent from Haemorrhoids operation.	
130		68	5.50	4870000	84	172	++	2 years cough and dyspnoea.	
143	M.	68	5.60	4820000	89	123	+++	Conval. Ac. Pleurisy	8 Aug.
			5.75	4780000	95	134			22 Aug.
101	M.	43	5.60	5770000	102	158	++	Oedema passing off.	6 July.
			10.90	6370000	110	132		Cyanosis & Vomiting.	31 Aug.
			6.25	5190000	100	160		Much improved.	4 Sept.
469	M.	64	6.00	6130000	90	200	++	Cardiac Weakness & Vomiting.	10 May.
			5.52	4950000	82	158		Very much better.	11 June.
331	M	56	6.05	-	96	172	(Calcified)	5 months cough & dyspnoea.	
106	M	68	6.25	5040000	100	170	++	Chronic Bronchitis, Very dyspnoeic and cyanosed. (died 24 hrs. later)	

Arterio-Sclerotic Cases.

The blood pressures in the cases shewn in the above table cover a wide range from 123 to 220, but in the majority of them the readings are distinctly high. All patients had moderate or marked thickening of the vessels and in one case the radial artery was absolutely calcified. The low pressure in case number 143 means that the heart is in poor condition after the attack of acute pleurisy; at the second examination a fortnight later the blood pressure is seen to be recovering.

We have already seen that a relationship exists between blood pressure and blood viscosity in health and in some conditions of disease. When a high viscosity has existed for a long time the increased strain will eventually tell on the vessels, producing first a phase of hypertonus which later would give place to arterial degeneration. But it must not be expected that high blood pressure and a viscous blood, will always be found in company. Even where a heightened blood viscosity has been the root of the trouble it may have disappeared long before the vascular disease manifests itself, for, with the onset of degeneration in the circulatory system, conditions of filtration and metabolic exchange become altered and so change the composition of the blood.

The association of arterial disease and a high/

high viscosity might arise in another fashion. Where the blood pressure reading is not simply an interpretation of increased arterial resistance but the pressure in the flowing blood is actually raised, this will lead to increased transudation and concentration of the blood.

In the above table of definite arterio-sclerosis cases the majority of the viscosity readings are somewhat higher than normal. Some apparently are still within the normal range but when it is noticed that most of the patients are beyond middle life it will be seen that the figures are indeed raised.

Some of the cases require special mention. No.8 was a young girl of 23 who suffered from very advanced disease of her kidneys and was just recovering from an acute exacerbation of the condition. Her blood pressure was very high and could not be kept down by medicinal treatment. The high reading was believed to be largely due to spasms of the arteries. No.101 owes the relative lowness of his first viscosity value to traces of a disappearing oedema, and the great height of his second estimation to an attack of acute gastro-enteritis with vomiting, - the associated collapse would account for the low blood pressure figure at this time.

Some of the cases at the foot of the table shew commencing circulatory failure with some cyanosis or dyspnoea.

Aneurism Cases.

TABLE 22.

Case	Sex	Age	Visc.	R.B.C.	Hb.	B.P.	Vessel Wall.	
212	M.	51	4.25	4590000	80	162	++	29 June.
	5 years history. (Been on KI. for weeks)							
85	M.	34	6.87	5100000	100	162	+++	
	Dyspnoea and Cyanosis marked.							
			6.10	5080000	100	156		7 July.
	Breathing easier. (Been having KI.) Looks much better now.							

Only two patients suffering from aneurism were examined. Both had thickened vessels and high blood pressures.

The first case (No.212) had been under treatment with potassium iodide for several weeks and was really in very good condition. His haemoglobin and red cells are diminished and the viscosity seems to correspond to these figures.

The other subject (No.85) was first seen when his breathing was bad. A second examination 9 days later shews a reduction in the viscosity and the blood pressure, though the blood count is practically stationary. He was also under treatment with potassium iodide, but the alteration in the viscosity is probably not due to this but to the improved aeration of the blood.

Hemiplegia Cases.

TABLE 23.

Case	Sex	Age	Visc.	R.B.C.	Hb.	B.P.	Vessel.	
478	M.	24	4.32	4080000	74	130	-	10 days history. Followed accident. Probably Mid-meningeal Haemorrhage.
492	F.	48	4.45	3650000	70	140	+	18 months old hemiplegia. Now Carcinoma of Sigmoid.
335	F.	40	4.95	5200000	76	230	++	5 days after onset.
339	M.	67	5.60	4850000	88		++	
83	F.	64	(5.62	5100000	102	149	+++	6 days history.
			)4.62	5020000	90	142		4 hrs. after 10 ozs. blood withdrawn.
			(5.10	5570000	92	140		A week after venesection.
344	F.	54	)5.62	4790000	94	160	++	Recent Case. (24 Jan.)
			(5.45	4690000	78	145		Bled 6 ozs. on 24th. (26 Jan.)
			)4.25	4100000	70	195		Going to Convalescent. (26 Feb.)
488	F.	44	(6.25	3650000	70	212	+++	Pontine Haemorrhage on 30th May.
			)					Bled 3 times between May 30 & June 4.
			(8.15	-	110	165		Died next day (5 June)
434	F.	68	(7.05	5470000	102	154	+++	6 days history (10 April)
			)7.17	4530000	100	120		More conscious. (12 April)
			(5.95	4780000	98	-		Speech returning. (14 May)
475	M.	46	(5.00	4950000	98	95	+	Old Syphilis (21 years ago)
			)					Became hemiplegic to-day. (15 May)
			(5.15	-	-	120		(19 June)
522	F.	55	7.35	-	-	-	+	Cerebral Thrombosis.
477	N.	28	10.08	5240000	110	142	++	12 days before examination patient left work/

work complaining of headache and was diagnosed influenza. A week later he suddenly became hemiplegic and remained unconscious until his death a few hours after he was examined. At P.M. he was found to have a small aneurism on the circle of Willis and around this a small amount of extravasated blood. There was extensive atheroma of the great vessels and of the heart valves.

Most of the cases in table 23, owe their hemiplegia to vascular degeneration and cerebral haemorrhage, a few to other causes.

At the top of the list stand three cases with low viscosity readings, which in some of them may be due to actual loss of blood.

The first case (478) was a healthy young man who fell when intoxicated and developed hemiplegia a few hours later. He did not come to Hospital till 10 days afterwards. It will be noticed that his radial vessel was not palpable and his blood pressure was normal. His recovery was rapid. The results in this case offer a sharp contrast to the rest of the readings.

The second case (492) was an old hemiplegia of 18 months standing who was now suffering from carcinoma of the sigmoid to which her anaemia could be attributed.

Number 335 has a normal viscosity with a high red count and a relative paucity of haemoglobin.

The remaining cases have all an increased blood viscosity and some a high corpuscular figure too. Some of the very high results may be due to malaeration of the blood while the patients were still comatose.

The beneficial effects of venesection in cases of cerebral haemorrhage are illustrated by numbers 83 and 344. Number 488, a case with multiple pontine haemorrhages, shews no such improvement, but became worse and worse in spite of repeated bleedings which apparently were insufficient to dilute the blood.

No.434, had only a relatively low blood pressure and was treated without venesection. The high viscosity present shortly after the haemorrhage gradually fell but was still above normal five weeks later. The haemoglobin in this case remained practically constant.

The blood pressure in most of these hemiplegia cases was distinctly raised and the radial vessels were more or less thickened, and like the cases of arterial disease in table 23, they probably had a high viscosity before the onset of the lesion. In the examples above, where several examinations have been made, the readings are usually highest soon after the haemorrhage has occurred. This may be due to the unconscious state of the patient, or it may/

may be that some concentration of the blood has actually determined the haemorrhage by raising unduly the already high blood pressure.

Varicose Veins, Haemorrhoids, etc.

Twelve estimations were made in cases shewing venous dilatation. Most of the readings lay within normal limits. In two patients where the figures were slightly raised, the red corpuscles were well over five million.

Nephritis Patients.

TABLE 24.

Case	Sex	Age.	Visc.	R.B.C.	Hb.	B.P.	Urine Ozs.	Oedema	Onset.	Remarks.
128	F.	39	2.75	3.16	40	134 P.	18+	++	6 months	"Chronic"
301	M.	41	An old syphilitic case with aortitis.						10 mths+	"Chronic"
	(Oct. 25)		3.45	3.45	65	145 P.	80	+++	and ascites.	
	(Nov. 15)		3.70	3.12	62	140 P.	12+	++	(Digitalis and dry cupping)	
			Suffered from frequent epistaxis and died Nov. 19.							
468	M.	65								
	(May 10)		3.87	3.45	50	194 PP.	20	++	? 2 weeks	Acute.
	(June 11)		3.50	3.79	54	142 PP.	27	++		
446	M.	46							Indefinite.	"Chronic".
	(April 20)		3.78	3.84	60	130 S.	5	++	Has been acutely ill for 2 days.	
	("	27)	4.25	4.45	61	138 S	15	less		
494	M.	7	3.75	3.01	59	-	10	Trace	1 day	Acute.
448	F.	14	4.37	4.74	79	145-	17	+	?	Acute.
473	M.	10	Had first attack of nephritis a year ago. 2 days present history.							
			4.50	4.90	80	92-	28	+++		Acute.
			Examined immediately after dry cupping.							
65	M.	26	4.50	4.92	87	165 P	76	+	3 weeks	Acute.

(Continued.)

Case	Sex	Age	Visc.	R.B.C.	Hb.	B.P.	Urine Ozs.	Oedema	Onset	Remarks.
343	M.	12		Patient developed a cerebral abscess from an old otitis. Had been passing brown urine for some weeks.						
			4.55	4.20	68	-		Trace.	Indefinite	Acute.
294	M.	41								
	(Oct.	6)	4.52	4.88	96	174 P.	26	+++	16 days	Acute.
	("	17)	.	Had hot air baths every day till Oct. 13, then on alternate days.						
	("	17)	6.05	5.28	99	160 P.	60	+		
391	M.	60		Very thin, parched subject. History indefinite.						
	(Feb.	22)	4.57	4.40	71	124 S.	65	++		Chronic.
				Diuretics began on 24th. Milk till 25th, then light diet.						
	(Feb.	26)	4.55	4.69	82	130 S	67	Oedema rapidly disappearing.		
335	F	40		Insidious onset, high blood pressure, hemiplegia 4 days ago.						
			4.95	5.20	76	230 PP.	22	Nil.		
5	F.	55		Illness began April 16th - suddenly became comatose and had a temporary paresis of Left side.						
	(June	2)	5.00	4.92	92	180 S	20+	Nil.		
	(Aug.	3)	5.00	5.03	94	180 S	38+	"		
				Being treated with hot air baths, Erythrol tetranitrate and Pot. Iodide.						
312	M.	45		First attack 15 months ago, many attacks since.						
			5.25	4.85	95	120 PP	92	Nil.	2 days history.	
				Much headache and bronchitis present.						

Case	Sex	Age	Visc.	R.B.C.	Hb.	B.P.	Urine Ozs.	Oedema	
340	M.	58	Had a previous attack 9 months before. Now breathless and very cyanotic from cardiac dilatation.						
			5.82	5.21	82	178 S.	12	+++	4 weeks history.

Case Number 201, a male aged 37, took nephritis 18 months before examination and had several attacks since then. He complained of headache, dyspnoea, drowsiness and pain in the back. No oedema noticed by patient.

(Aug. 29)	5.95	4.68	92	152 PP.	66	Nil.	Subacute.
(Sept. 1)	4.50	4.80	92	146 PP.	+	"	
(" 2)	Began to vomit all his food. Headache greatly increased.						
(" 6)	5.90	4.57	92	150 PP.	30	"	
	Drycupping and Hot air baths began on the 6th.						
(" 28)	4.73	4.78	92	120 PP.	+	"	Much better now.

334.	M.	25.	Chronic case with chronic Bronchitis, dyspnoea and cyanosis, and occasional vomiting, but no oedema.						
			7.02	4.67	98	125 P.	46	Nil.	5 weeks history.

101. Case of Male, aged 43, a labourer who enjoyed moderate health until 18 days before examination, when he began to complain of dimness of vision (retinal haemorrhage) and vomiting. Swelling of ankles began 3 days later. No cardiac disease but some accentuation of aortic second sound, some thickening of the arteries and a high blood pressure. Slight dyspnoea and trace of oedema of legs on admission - none now. Been on Erythrol tetranitrate.

	V.	R.B.C.	Hb.	B.P.	Vessel	Urine	Oedema
6 July	5.60	5770000	102	158	S	46	Nil. Improving.

Discharged from hospital on July 10th and remained fairly well till Aug. 30th when suddenly was seized with severe diarrhoea and frequent vomiting accompanied by cramps in legs and arms. These symptoms continued after his admission to hospital on 31st August. He was then somewhat cyanosed and had a very feeble pulse.

	V.	R.B.C.	Hb.	B.P.	V.	Urine	Oedema.
(31st) (Aug.)	10.90	6370000	110	132	P+	10 ozs	Nil. Bism.Salicyl.
(4th) (Sept)	6.25	5190000	100	150	P.	46	-

Symptoms quite gone now, no cramps, diarrhoea nor vomiting.

The/

The nephritis cases were originally arranged according to their clinical diagnosis under the headings, - "acute, "subacute" and "chronic", but this was found to be unsatisfactory. All the "acute" cases shewed a reduced blood viscosity but the same condition was found in many of the examples of "Chronic Bright's". Cases of chronic renal disease are liable to light up at any time, and many of the so-called "acute" cases are merely exacerbations in the course of a latent or insidious subacute or chronic condition. Little reliance can be put on the patient's history of the duration of his ailment, unless the onset has been quite recent.

It appeared likely that the condition of the blood would depend, not so much on the length of time the disease had lasted, as on the present efficiency of the kidneys in secreting urine and getting rid of waste products, so the cases were all slumped together and arranged according to the viscosity reading given by them. The results are interesting. The extremes are far apart but the cases naturally fall into three groups, those within normal limits, cases above, and cases below these figures.

The majority of the nephritis cases fall into the/

the hypoviscous group with readings from 2.75 - 4.57. They include all the real, acute, cases and the cases of longer standing, who have sought re-admission to hospital for a fresh attack. In all these cases more or less oedema was present, and in most of them the secretion of urine was low. The viscosity does not vary in constant fashion with either of these columns.

Granular and hyaline casts were present in all these cases, and in some, especially those near the top of the list, blood and epithelial casts also appeared. The amount of albumin found in this series varied from a mere trace to 9 grains per ounce, and again it was noticeable that the most severe cases were those with the lowest blood viscosity.

The red blood cells and the percentage of haemoglobin on the whole increase with the viscosity, but the ratio is not quite strict. In the lower ranges the viscosity is a little greater than the blood counts warrant, and in the higher reaches the reverse holds good. The smaller figures at the top of the list are to be looked upon as due to hydraemia, while at a later stage a true anaemia makes its appearance. As will be seen from the table, this secondary anaemia tends to counteract the rise in viscosity that is produced under treatment with hot air baths and diuretics.

The/

The blood pressure is raised in most of this group, but the high figures are not specially collected at either end of the table. The condition of the vascular wall also varied very considerably (P = palpable, P.P. = very distinct, S. = sclerosed.) With a diminished viscosity a low blood pressure would be expected (as in anaemias) but that is not the rule in nephritics. When hydraemia is present a large amount of the surplus fluid can be accommodated in the venous and capillary lakes, but if the arterial system is also overfilled the blood pressure must rise. It may be that the increased pressure in such cases is the result of the direct stimulation of the arterial walls by retained "pressor" substances, but more likely it is the response by some regulating mechanism (e.g. the suprarenals) to the call for a heightened pressure in the kidneys to enable them to continue the secretion of urine.

The three cases shewing normal blood viscosities are all chronic cases where no oedema is present.

All have thickened arteries and two of them shew a very high blood pressure. No.335 was really admitted for hemiplegia but was found to be passing only a small amount of urine daily with a fair quantity of albumin in it.

The/

The hyperviscous cases are also chronic nephritics. Oedema is absent except in one of them - No.340 - who really owes his high viscosity reading and his inclusion in this part of the table to his cardiac dilatation and consequent cyanosis. The same condition explains the result found in number 334.

The remaining two cases - numbers 101 and 201 - would also fall within the higher ranges of normal were it not for the blood concentration consequent on persistent uraemic vomiting.

Twelve patients convalescent from acute or subacute nephritis were also examined. Their readings lay betweem 4.15 and 6.00. Only one was above normal and four were below 4.70, the remainder shewed nothing of note.

Hirsch and Beck (1902) and Kottmann (1907) expecting to find in cases of nephritis a high blood viscosity which would fit in with preconceived ideas and explain the increased blood pressure, were surprised to find that it only occurred exceptionally. A diminished viscosity is also recorded in these cases by Austrian (1911), Bachmann (1909), Bence (1906), Rotky (1907) and McCaskey (1908.

Some/

Some interesting observations were made by Segale (1907) in experimental anuria. Ligature of the vessels at the hilum or extirpation of a part of the kidneys produced the same results - a more or less marked reduction of the blood viscosity after 24 hrs, later there might be further diminution or a slight rise.

In all cases where he ligatured the ureter he found increase of the viscosity - sometimes to a very considerable degree.

Brandau (1917) employs the viscosity estimation in cases of renal and cardiac disease as an index for treatment.

Where both viscosity and blood pressure are raised he advocates purgation and venesection.

In cases with high B.P. but low viscosity, purgation is indicated but venesection should be avoided.

Purgatives are dangerous where a low blood pressure is associated with a viscous blood, since they would increase the viscosity and add to the embarrassment of the enfeebled heart. Venesection might be useful here by promoting diuresis.

Acute Lobar Pneumonia.

TABLE 25.

Case	Sex	Age.	Visc.	R.B.C.	Hb.	W.B.C.	Temp.	Resp.	Pulse	Day	Remarks.
435	F.	32	4.55	-	-	13700	102°	36	152	4	Double. 7 months pregnant.
289	F.	45	5.47	3460000	86	17200	103°	52	128	4	Left lower lobe.
288	M.	27	5.63	-	85	16000	104°	48	114	3	Right upper.
342	M.	31	5.85	4400000	80	16100	100.2°	28	94	9	Right lower.
			4.48	3500000	60	16000	102°	30	100	42	Unresolved.
432	M.	57	5.75	3240000	88	17100	100.4°	-	-	2	Right lower.
401	M.	16	5.75	3950000	70	10000	100.8°	24	96	6	Left lower.
470	F.	36	5.76	4270000	90	19900	103.2°	38	116	5	Rt. Lower & Mid.
369	F.	23	5.75	4750000	70	11000	102.2°	24	108	4	
347	F.	11	5.87	-	78	8400	102.4°	28	118	2+	
413	M.	39	5.87	4700000	92	10600	102.8°	36	100	5	Left lower.
459	M.	65	5.90	5090000	100	15500	102.2°	48	104	14	Left upper.
300	M.	18	6.12	5110000	100	22900	100.6°	24	96	3	Right upper
299	M.	42	6.20	4900000	90	12800	101°	40	96	4	Left lower
			5.50	4910000	90	7300	96°	24	76	21	Getting up.
447	M.	18	6.03	5700000	88	8200	100.8°	30	122	5	Comatose.
			7.25	-	-	8000	98°	30	92	7	Had crisis to-day.
523	M.	31	7.40	4340000	90	15000	105.6°	50	102	3	Right lower.
460	M.	40	7.78	4620000	92	14000	100°	30	96	4	Extremely collapsed. Right upper.

Most of the pneumonia cases have been examined early in the disease, a few at later stages. Practically all shew a distinct increase in the blood viscosity which in some cases is markedly raised. At the same time the red blood corpuscles and the haemoglobin are somewhat low and the viscosity is much greater than these counts would warrant.

The temperature, the pulse and respiration rates and the leucocytes are all increased to varying extents and none of them shew any relation to the amount of viscosity augmentation.

The skin was flushed in many cases but the viscosity did not appear to correspond in any way to the amount of perspiration present.

The viscosity did not alter at different stages of the disease, but a fall takes place after resolution has set in. Ten patients convalescent from pneumonia were also examined at periods from 2 - 6 weeks after the crisis. In these the viscosity readings were either normal or about 4.50, the exact figure depending on the degree of anaemia present.

The first case on Table 25 was a woman seven months pregnant who had been indefinitely ill for 4 days and now shewed signs of commencing consolidayion at both bases. She was probably very anaemic but there was no opportunity of examining the red cells/

cells or haemoglobin.

With the exception of this patient, all the cases shew viscosities above the normal and the more seriously ill gravitate to the foot of the list.

Case 342, when examined on the 9th day, gave a comparatively low reading and five weeks later when the condition was still unresolved, the reading was very much lower, corresponding with the anaemia which had developed.

Austrian (1911), Bachmann (1909) and Ramjanzew (1914) all draw attention to the heightened viscosity seen in pneumonia cases. Austrian attributes the increase to the effects of cyanosis and salt retention, while Bachmann states that the number of R.B.C. and W.B.C. and the carbon dioxide content have no influence in these cases since the changes are only found in the milder ones. Bachmann blames the increased amount of albumin in the plasma, and this finding is confirmed by Trumpp (1911) who states that in pneumonia the difference between the viscosity of the total blood and that of the same blood defibrinated is 14%, whereas in the normal case the difference only amounts to 5%.

TABLE 26. Shewing Acute Pleurisy Cases.

Case	Sex	Age	Visc.	R.B.C.	Hb.	W.B.C.	Temp.	Pulse	Resp.	Days	Remarks.
501	M.	43	3.75	4040000	70	7800	96.6°	72	20	10 days	Much effusion, with oedema of back and legs.
429	M.	21	4.55	4930000	76	-	101.4°	92	24	-	With Effusion.
349	M.	13	)4.70	3720000	62	10000	100.2°	118	26	16	Effusion up to clavicle.
			( )								
			(4.75	4480000	65	8300	100°	104	28	14 days after tapping.	
519	M.	13	5.10	3340000	67	24000	101°	114	26	3	Also some broncho-pneumonia present.
402	M.	15	5.80	4910000	84	6000	101.4°	96	20	14	Slight effusion.
322	M.	35	5.80	5041000	98	4500	97°	72	24	8	Much fluid.
422	M.	56	6.25	4080000	89	16250	100.2°	80	20	3rd May.	Much fluid present. Tapped after examination.
			5.25	3690000	82	-	97.6°	72	24	5th May.	2 days after paracentesis.

Case 363, a man aged 49, had had a cough since the beginning of December. Admitted to Hospital on Jan. 31st complaining of shortness of breath. His right chest was dull up to the 2nd interspace. 40 ozs. of fluid withdrawn.

8th Feb.	5.62	4850000	80	5400	100.4°	100	24	Tapped afterwards.
23 Feb.	4.95	4970000	85	8400	101.2°	96	24	Dulness increasing.
27 Feb.	Tapped again.							
6 March	4.82	4810000	80	6200	100.8°	96	22	
22 March	28 ozs. withdrawn from chest.							
17 April.	4.00	3240000	55	10000	100.6°	92	20.	

In the above table of acute pleurisy cases the blood viscosity is found to range from 3.75 to 6.25, thus including both low and high figures as well as many normal ones. These results seem to correspond fairly closely with the red blood corpuscle figures and the percentage of haemoglobin present. No such relation to the temperature or to the pulse and respiration rates can be made out. Most of the cases shewed a good deal of perspiration but this does not seem to have influenced the results.

The first case (No.501) owes its specially low figures to the enormous amount of oedema present. The quantity of the effusion into the pleural cavity does not apparently affect the blood viscosity.

In case 349 the viscosity reading has risen together with the other blood figures, fourteen days after tapping.

A reduction in all three items occurrs in No.422, two days after the removal of a large quantity of exudate; and in No.363 where the chest continued to fill up after each withdrawal of fluid, the drain on the system resulted in a considerable degree of anaemia and a greatly reduced viscosity reading.

A comparison of these results with the figures found in the pneumonia cases is interesting.

On the whole the temperature, the pulse and respiration rates are all a little lower in the pleurisy/

pleurisy cases, while the leucocytosis is not so marked as in the pneumonias.

In both tables the blood counts are approximately the same, but the pneumonia cases shew higher viscosity readings.

The different level in temperature is not sufficient to account for this, since we have already shewn that at the same temperature the pneumonic blood is more viscous than that of a pleurisy case. Nor does it seem to be due to the higher number of leucocytes present in the circulating blood in the pneumonias. Again, a large effusion up to the clavicle will knock out a good deal more of the lung tissue and cause greater cardiac embarrassment than the consolidation of a single lobe, and yet in such a case (No.349) the respiratory rate only rose to 26 and the viscosity stood at 4.70. The cause of the dyspnoea in pneumonia apparently depends on something more than reduction of the aerating surface in the lungs, and is probably to be looked for in the presence of abnormal acids which may stimulate the respiratory centre just as carbon dioxide does. (Wells, Chemical Pathology p.560). Lewis and Barcroft* have shewn that such an acidosis does exist in pneumonia and is often very well-marked. This acidosis /

* Lewis & Barcroft 1915 Quart. Journ. Med. (8) p. 108.

acidosis will alter the blood viscosity by interfering with the distribution of water and salts between the corpuscles and the plasma in the same way as carbon dioxide. In lobar pneumonias where large numbers of cells are being broken up, - first red cells and fibrin and later white cells, - a large amount of waste material will be carried into the blood stream and doubtless this also tends to raise the viscosity of the plasma.

Further, it is generally accepted that in pneumonias the amount of fibrinogen in the blood is greatly increased and this again must add to the thickness of the plasma and so influence the total blood viscosity.

Chronic Bronchitis.

TABLE 27.

Case	Sex.	Age	Visc.	R.B.C.	Hb.	Resp.	Pulse.	Remarks.
482	M.	71	4.25	3840000	65	16	70	With Chronic Rheumatism. Only slight cough.
360	M.	79	4.72	4800000	86	24	86	Oedematous and very Dyspnoeic.
243	M.	43	5.25	4790000	89	22	84	Convalescent.
312	M.	45	5.25	4850000	90	20	76	Many crepitations present.
43	M.	35	5.25	5060000	100	20	78	Concalescent.
309	M.	28	(5.95)	5320000	96	36	116	Asthma and Emphysema. Very Cyanotic (Urine 12 ozs.)
			( )6.25	5170000	102	40	114	Cyanotic and oedematous (Urine 16 ozs.)
331	M.	56	6.05	——	96	24	86	Some arterio-sclerosis.
106	M.	68	6.25	5040000	100	38	(84-140)	Moribund. Some cyanosis and dyspnoea. Much oedema. (Urine 8 ozs.)
334	M.	-	7.02	4670000	98	20	76	Cyanosis - no oedema.
404	F.	40	9.75	5570000	106	44	128	Very Cyanotic, with considerable dilatation of Right heart. Had a chronic cough for years, but has been much worse during last 5 days. Died 2 days later.

The first case shewn on the above table was a feeble emaciated old man whose chief complaint was "rheumatics" and who had a slight cough but no dyspnoea nor sign of heart failure.

The remainder of the cases were chronic bronchitis of long standing, who had sought admission to hospital for an exacerbation of their condition or for a fresh "cold".

Amongst the cases shewing normal viscosity figures are two convalescents who had sufficiently recovered to be able to walk about quite comfortably.

Number 360, who had a low viscosity just within the limits of normal, owed his figure to the antagonistic actions of hydraemia and cyanosis.

Number 312, who also had a normal reading, suffered from chronic disease of his kidneys and was passing large quantities of urine. There was no oedema present at the time of examination.

The other patients all had a blood viscosity reading above the normal and owed this to the cyanosis and heart failure from which they suffered. Some of them shewed oedema as well.

The altered viscosity of the blood in these cases is to be looked upon as due to mal-aeration in the lungs - from passive congestion, emphysema, etc., and to the defective character of the circulation, which/

which allows too slow a passage through the systemic capillaries.

The results in this series contrast with the findings in both the pneumonias and the pleurisies.

Two other lung cases might be mentioned at this point.

The first, a young man of 24, who had suffered from bronchiectasis for many years had a blood viscosity of only 4.90 in spite of the fact that he was running an irregular temperature. His blood shewed 4710000 red cells with 85% haemoglobin.

The other case was a woman of 45 who had an extensive involvement of her lungs by new growth secondary to scirrhus of the breast. An examination of her blood shewed evidences of pulmonary insufficiency - her figures were, - Viscosity 6.75, R.B.C. 5520000 and Hb. 94%.

Pulmonary Tuberculosis Cases.

TABLE 28.

Case	Sex	Age	Visc.	R.B.C.	Hb.	W.B.C.	Remarks.
341	F.	22	4.00	4650000	46	9000	Confined to bed.
39	M.	6	4.70	4310000	78	-	
108	M.	16	4.80	4760000	97	-	Tub. pleurisy with effusion.
93	M.	45	5.12	4890000	80	6200	Quiescent phthisis.
225	M.	54	5.50	4780000	92	4100	
			5.63	4580000	92	5600	
493	M.	42	5.72	4410000	88	5100	Confined to bed.
29	M.	38	5.80	4390000	80	16300	
61	M.	49	5.88	4920000	82	5400	
123	M.	21	6.05	5030000	100	7200	
27	M.	41	6.25	3870000	75	-	Tuberculous pleurisy.
21	M.	32	7.20	5010000	90	-	" "

Patients suffering from pulmonary tuberculosis would be expected to shew variations in their blood viscosity corresponding with the amount of lung involved, the temperature, the amount of perspiration and the degree of anaemia. With two exceptions the patients included in the above list enjoyed fairly good health and were living an open air life. More than half of them have viscosities above the normal limits. Similar results are quoted by Bachmann (1909), Trumpp (1911) and Robert-Tissot (1907). The last author suggests that the increased viscosity is due to carbon dioxide increase and alkali diminution in the blood in these cases. He bases his argument on the statements of Robin and Binet who shewed at the Tuberculous Congress in London in 1901 that in 92% of phthisis cases the oxygen consumption and the production of carbon dioxide are augmented, and that an exaggerated gaseous combustion was one of the characteristics of the terrain liable to infection with the tubercle bacillus.

Since my best cases were those with raised viscosity readings I cannot subscribe to the findings of Osler and Lamb (1912) who believe that a low reading is of good prognosis.

The/

The low figures in the first case on the list correspond with the poverty of haemoglobin. The readings in the three following cases are about normal when the ages of the subjects are considered.

The great increase in the blood viscosity found in the two cases of tuberculous pleurisy at the foot of the table is very striking.

TABLE 29. Tuberculosis.

Case	Sex	Age.	Visc.	R.B.C.	Hb.	
186	M.	16	4.62	4340000	89	Tuberculous Hip.
187	M.	17	4.30	3730000	89	Tuberculous Hip.
54	F.	20	4.45	3470000	60	Tuberculous Salpingitis.
205	M.	3	4.57	4480000	86	Tuberculous Hip.
98	M.	45	4.70	4630000	90	Tuberculous Adenitis (and Scurvy)
196	M.	15	4.76	4800000	90	Tuberculous Ankle.
125	M.	22	4.87	4920000	92	Tuberculous Adenitis.
138	F.	18	5.05	4770000	83	" "
134	F.	6	5.12	4620000	88	Tuberculous Spine.
428	F.	44	5.13	4860000	96	Tuberculous Meningitis.
17	M.	11	5.40	4560000	88	Latent Tubercle
77	M.	32	5.45	5490000	96	Tuberculous Testis (excised)
113	M.	31	5.50	4580000	100	Tuberculous ankle (amputated)
56	F.	14	5.62	3800000	82	Tuberculous Adenitis.
92	M.	19	5.75	4910000	85	Tuberculous ulcers on leg.
99	M.	29	6.13	5220000	98	Tuberculous ankle.
110	F.	11	6.25	4880000	88	Tuberculous keratitis.

The cases of tuberculosis collected on Table 29 were examined under similar conditions. The readings in the majority of them fall within normal limits, while only a few exceed or fall short of these figures. This contrasts sharply with the findings in the pulmonary cases and is somewhat remarkable when it is considered that in some of the chest cases the amount of lung involved was comparatively little.

The cases on this table do not group themselves into classes. Three hip joint cases are amongst the lowest viscosity readings, but other joint cases appear far down the list.

Bachmann (1909) thinks his $\frac{Hb.}{V}$ quotient particularly valuable in differentiating tubercle from typhoid. His figures emphasise the difference between pulmonary and other tubercle. In pulmonary tuberculosis the quotient varies from 11.5 - 16.6 and in other manifestations from 14 - 18. The low quotient figures simply express in another way that the viscosity is high relative to the percentage of haemoglobin. A high $\frac{Hb.}{V}$ quotient is found in typhoid where the loss of albumin gives an impoverished blood and a low viscosity.

Malignant Disease.

TABLE 30.

Case.	Sex	Age	Visc.	R.B.C.	Hb.	Remarks.
481	F.	67	2.3	2750000	30	Sacroma duodenum (Secondary in Liver)
87	M.	45	3.62	3830000	70	Carcinoma Stomach (gastrectomy)
492	F.	48	4.45	3650000	70	Carcinoma Sigmoid.
457	M.	32	(4.25)	5020000	94	Supposed abdominal Tumour. 24 April.
			(4.88	-	-	27 April.
67	M.	46	4.50	4210000	80	Inoperable Malignant disease abdomen.
414	M.	51	(4.95)	4520000	84	Neoplasm of Pancreas (Jaundice) 5 March.
			(4.32	3830000	60	" " " 2 April.
45	M.	41	6.75	5100000	96	Intestinal Neoplasm with compensated Cardiac Disease.
397	F.	45	6.76	5500000	94	Secondary Scirrhus Lungs. (breast removed 2 yrs.ago.)

Practically all the patients suffering from malignant disease, whom I examined, shewed a thin blood, the low viscosity being associated with a corresponding poverty of red corpuscles and haemoglobin. This anaemia may arise from haemorrhage, or from some toxic action on the blood or bone marrow. It is also probable that the malnutrition found in such cases leads to impoverishment of the plasma solids and so tends to keep the blood viscosity low.

The figures in this table are very similar to those of the secondary haemorrhage cases, where loss of red corpuscles and dilution of the plasma go hand in hand.

The last two cases are exceptional. In both of them there is a slight compensatory polycythaemia which would partly account for the high readings. There was probably also an increase of the CO_2 content in the blood of these cases.

Cases shewing Jaundice.

Haro, so far back as 1876, noticed that the addition of bile salts to oxalated blood raised its viscosity to a considerable extent and suggested that the increased thickness of the blood accounted for the slow pulse of jaundice.

Rotky (1907) and Austrian (1910) both comment on the high readings found in these cases and also note that the plasma viscosity is increased as well as the total viscosity. In some cases Rotky found the viscosity of the plasma raised altogether the number of red blood corpuscles and the total blood viscosity remained low.

TABLE 31/

TABLE 31. Jaundice.

Case	Sex	Age	Visc.	R.B.C.	Hb.	Pulse	Remarks.	
476	F.	53	3.65	3071000	61	96	Malignant Liver.	
443	F.	56	4.38	3990000	80	108	Very deeply jaundiced.	
				A case of neoplasm who died 5 days later.				
509	M.	47	4.62	4210000	82	64	New growth.	
414	M.	51	4.95	4500000	84	56	Malignant Pancreas	(5 March)
			4.32	3830000	63	56	" "	(2 April)
390	M.	24	6.50	5150000	84	80	Cirrhosis of Liver. On admission to Hospital.	(22 Feb.)
			6.10	4480000	80	88		(26 Feb.)
			6.87	4790000	92	120	Deeply bronzed.	(10 April)
				Patient died May 22nd.				

Of the five jaundiced patients I had an opportunity of examining, four owed the pigmentation to the presence of malignant disease in the liver or pancreas. In all these the viscosity readings were lower than normal on account of the poor haemoglobin and low corpuscular figures.

The fifth case is of quite another kind. The patient, when admitted to the Infirmary, shewed a greatly enlarged liver and some increase in the splenic dulness. He was deeply jaundiced and was diagnosed as a case of Hanot's cirrhosis. At all examinations the viscosity was very high - greatly in excess of what would be expected from the number of the red cells and the percentage of haemoglobin present. These results suggest an alteration of the plasma viscosity.

Cases of Cirrhosis of the Liver.

In addition to the case of Hanot's disease mentioned above, two other cases of liver cirrhosis were examined. These shewed no jaundice.

The first (No. 437) gave the low viscosity figure of 3.87 his blood estimates being, - R.B.C. 3210000 and Hb. 60%. The severe anaemia in this case was brought about by frequent epistaxis.

The/

The readings in the other case were practically normal.- V = 5.03, R.B.C. 4651000 and Hb. 80%. The patient was a woman aged 30, who had a good deal of ascites and some temperature.

Gallstones.

The viscosity figures in four out of five patients suffering from gallstones were slightly above the normal level, the fifth was normal.

TABLE 32. Gastric Conditions.

Case	Sex	Age	Vis.	R.B.C.	Hb.	Remarks.
358	F	39	3.82	3800000	57	Gastric ulcer - Haematemesis.
109	F	-	4.05	4140000	78	Gastric Ulcer.
24	M.	64	4.50	3700000	70	Haematemesis (cause unknown)
244	F	23	4.65	4620000	88	Hyperchlorhydria.
132	F	37	4.65	4690000	89	Atropic Gastritis.
73	F	20	4.80	4760000	92	Gastric Ulcer (Convalescent)
368	M	35	7.25	4550000	98	Haematemesis, Much vomiting.

The figures in all these cases except the last two, are somewhat below the proper level. This low viscosity, of course, is the direct sequel of Anaemia and is due to the loss of blood, or insufficiency of the nourishment taken by the patients.

The convalescent gastric ulcer case gives satisfactory figures.

In the case of Number 368, the extraordinarily high result was produced by concentration of the blood following several days persistent vomiting.

Other abdominal conditions examined, include Latent Typhoid, diarrhoea and vomiting, appendicitis cases convalescing after operation and a case of hydatids of the liver. There was nothing very characteristic about the results in these cases. All gave rather low figures corresponding with the degree of anaemia shewn.

TABLE 33. Diseases of the Nervous System.

Case	Sex	Age	Visc.	R.B.C.	Hb.	Remarks.
58	F	13	4.45	4710000	76	Chorea.
137	F	13	4.55	4800000	89	"
34	F	11	4.56	5080000	90	"
405	F	12	4.92	4650000	87	"
290	M	15	4.70	-	85	Epilepsy.
20	M	22	5.25	4820000	95	Neurasthenia.
126	M	30	5.60	5090000	95	"
28	M	38	6.00	498000	95	"
204	F	25	5.50	4820000	93	Functional Tremor.
182	F	23	(4.25	4471000	87	Alcoholic Neuritis (24 Aug.)
			(4.79	4430000	89	" " (4 Sept.)
242	M	36	4.85	4550000	88	" "
102	M	43	5.35	4850000	97	Glycosurie Neuritis. (Sugar 4.2 grs. per oz.)
23	M	28	5.12	4450000	80	Disseminated Sclerosis.
50	M	45	5.73	4950000	95	Tabes Dorsalis.
44	M	19	5.90	4440000	95	Poliomyelitis Anterior Acute.
428	F	44	5.12	4860000	96	Tuberculous Meningitis. (Died 2 days later)
518	M	15	5.50	-	-	Pneumococcal Meningitis (? abscess)
511	M	14	5.65	4080000	72	Clinically Acute Meningitis. Died few hours after examination. No lesion found except congestion of the brain.
343	M	11	4.55	4230000	68	Cerebral Abscess (ear case)

The above table (No. 33) contains a miscellaneous collection of conditions affecting the nervous system.

The cases in the upper part of the list all have normal viscosities when the age and sex of the patient is kept in mind. The only exception is No.28, a neurasthenic, who has a slightly raised figure.

Numbers 182 and 242, two cases of alcoholic polyneuritis, shew rather low viscosity readings which contrast with finding in a case of diabetic neuritis.

The meningitis cases seem a little high; number 511 is especially notable when the patient's age and his blood counts are examined.

Cases of Rheumatic Fever.

TABLE 34.

Case	Sex	Age	Visc.	R.B.C.	Hb.	Temp.	Persp^{n}.	Duration	Remarks.
524	M.	35	4.25	3530000	69	103°	++	1 week	Joints only.
330	F.	19	4.57	3510000	32	100°	+	3 weeks	" "
427	F.	18	4.73	4560000	78	101.4°	++	3 weeks	" "
146	M.	16	5.02	4620000	94	97°	-	7 weeks	Convalescent pericarditis case.
419	F.	35	5.03	4780000	89	99°	++	2 weeks	Pericarditis commencing.
350	M.	19	5.50	4490000	80	100.2°	+++	3 weeks	Marked Pericarditis.
79	M.	58	6.00	4850000	92	98°	-		Convalescent case.
324	F.	37	6.35	4180000	67	99.4°	+++	3 weeks history.	Just admitted to hospital.

No. 495, a woman of 20, was admitted to the Infirmary after four days acute fever and joint pains. She had a very rough systolic murmur over the aortic area. Perspiration was very profuse at the time of examination.

(5th June)	4.05	2810000	70	102.6°	
(7th June)	4.75	3130000	64	101.6°	Pericardial friction.
(10th June)	5.02	3250000	63	101.4°	Pericarditis marked.

Most of the viscosity readings in the above table are somewhat low in spite of the fever and the copious sweating. The lowest figures are in uncomplicated joint cases, while those cases where pericarditis is present, shew slightly higher results. This is difficult to account for. The spread of the inflammatory process to a fresh serous cavity is insufficient to explain it, and the mechanical effect on the heart's movement in the early stages, must be but slight. It may be that when the inflammation attacks the pericardial surface, the subjacent muscle is also involved.

The changes in blood viscosity following the onset of pericarditis in a rheumatic fever case are well illustrated in No.495.

In this series of cases the leucocytosis ranged from 6300 to 17200. No relationship between the viscosity and the number of white cells present was evident.

The amount of perspiration and the height of the temperature do not appear to influence the results.

A case of long-standing adherent pericardium gave the following figures - V = 5.30, R.B.C. 4980000, Hb. 98%, which are practically normal for his age - 53.

Six cases of chronic rheumatism and rheumatoid arthritis were also investigated but shewed no characteristic departure from the normal.

Diabetes Mellitus Cases.

TABLE 35.

Case	Sex	Age	Visc.	R.B.C.	Hb.	
323	M	57	5.25	4750000	96	22 Nov.
			5.37	4690000	93	28 Nov.
102	M	43	5.35	4850000	97	
483	M	21	4.50	3910000	80	30 May.
			4.75	4040000	85	4 June
			4.55	4120000	85	14 June
7	M	18	6.25	5100000	100	12 June
			5.75	5160000	96	22 June

Opinions regarding the viscosity changes found in the blood of diabetics are a little at variance. Martinet (1912) says that the blood viscosity is raised in all diabetics and Austrian (1911) believes that the viscosity readings of both plasma and whole blood are high in such cases. Bachmann (1909) and Rotky (1907) could find no essential change, while Umber (1909) and Jorns (1909) report that they found some very high figures in diabetic coma. In this last condition the high viscosity of the blood is not so likely to depend on the amount of sugar as on the presence of other abnormal products.

Glucose though crystalloid in character, is a non-electrolyte and will only increase the viscosity in/

in proportion to the amount of it in the fluid. The quantity of sugar which occurs normally in the blood is an insignificant fraction, and even in hyperglycaemia it hardly increases sufficiently to directly alter the blood viscosity. But the increase of sugar may upset the balance between the blood and the tissues, and the polyuria associated with the condition will concentrate the blood and so increase its viscosity.

The table given above shews high, low and medium values.

Cases 323 and 102 had normal viscosity readings. They were passing from 40 - 70 ozs of urine daily, containing from 4 - 30 grains of sugar per ounce.

Case number 7, who was examined in the Convalescent House, had a high blood viscosity reading. His blood also shewed a fair degree of polycythaemia and he was passing large quantities of urine.

In contrast to this is a severe case (No.483) seen in the Infirmary. Although passing 140 - 150 ounces of urine daily with 30 grs. of sugar per ounce, the blood viscosity was distinctly below normal. It will be noticed that the other blood data are also low.

In this series of cases, the blood viscosity did not correspond in any way with the amount of urine evacuated daily or with its sugar concentration.

Thyroid Cases.

TABLE 36.

Case	Sex	Age	Vis.	R.B.C.	Hb.	B.P.	Remarks.
229	F	44	3.75	3570000	77	104	Exophthalmic Goitre. (Operation case)
			3.81	3490000	77		
293	F	43	4.05	4540000	80		Exophthalmic Goitre.
292	F	28	4.65	4700000	85		" " 18 months
513	F	20	5.4	3850000	70	122	" " 3 years.
82	F	36	3.95	4070000	78	135	Adenomatous Goitre (operative)
336	M	54	(4.50)	4530000	88	130	Myxoedema, albuminuria, slight cyanosis and much oedema.
			(4.12)	4450000	78	105	After 5 weeks Thyroid treatment.

It has been stated that the active principle of the Thyroid gland reduces the blood viscosity, while the lack of this substance tends to raise the viscosity. The evidence on which these statements are based, is not very convincing, e.g. Burton-Opitz (1904) stated that intravenous injection of Thyroid extract in dogs raises the blood viscosity, and in 1906 he observed that in dogs with thyroid enlargement the viscosity of the blood was low.

Fano and Rossi (1905) conclude from experiments on animals that the thyroid and the parathyroid hormones adjust and regulate the viscosity of the blood by altering its physio-chemical condition. They found that removal of both thyroid and parathyroid glands was followed by an increased viscosity and that the extirpation of the thyroid alone resulted in a still greater increase while if the para thyroids only, were removed, no such effect was seen.

Segale (1907) on the other hand, got constant lowering of the blood viscosity in removal of the parathyroids or of both these and the thyroid, but not when the thyroid alone was taken away. These experiments he repeated later, and in his 1913-14 paper he confirms his previous findings.

Determann (1910) could discover no difference in blood viscosity in his cases of Myxoedema and of Exophthalmic/

Exophthalmic Goitre.

All my thyroid cases (except one of Graves' disease) shew reduction of the viscosity figure, in fairly close relation to the diminished blood counts.

The findings in the myxoedema case are probably not typical of such cases, for the patient also suffered from albuminuria and had a great deal of oedema. The second estimation in this case taken after five weeks treatment with thyroid extract, might be cited as evidence in favour of its hypo-viscosing effect.

Food deficiency cases.

Scurvy.

Case	Sex	Age	Visc.	R.B.C.	Hb.	
439	M	29	4.25	3240000	45	Very anaemic.
98	M	45	4.70	4631000	87	Convalescent.
33	M	55	5.50	4420000	81	Convalescent.

Two of the scurvy cases were convalescent before they were examined. In one the viscosity reading is a little high and in the other a little low for their ages, but both are still within the normal limits. The first case also suffered from a considerable degree of anaemia, but the viscosity reading though lower than normal, is much above what would be expected with the haemoglobin and red corpuscle values shewn.

Beri-beri.

305	M.	27	4.25	4820000	92	Oedema present.
329	M	18	4.42	4510000	90	Oedema.
327	M	30	4.47	4980000	91	Slight oedema.
328	M	22	5.00	5010000	98	No oedema.

This batch of cases form an interesting group. They were big burly sailors from a Scandinavian sailing vessel which had arrived at Leith from South America. The boat had taken a month to sail from Peru to the Cape and during this time the crew had been/

been fed largely on preserved herring.

Weakness and swelling of the legs developed shortly after this as they were "crossing the line" about six weeks before they were examined in Edinburgh.

The viscosity readings in all four cases are low when compared with the remarkably good haemoglobin and red cell figures. It will be noticed that the viscosity values are in inverse proportion to the amount of oedema present.

CONCLUSIONS AND SUMMARY.

The present thesis is based on the results of examination of the blood viscosity and other data in upwards of 500 cases, and also includes an account of a large number of experiments done on the factors which influence blood viscosity in vitro.

Having first emphasised the importance of the blood viscosity in the economy of the body, and reviewed the history of the subject, we proceeded to consider the physical laws involved. We then examined the different types of viscosimeter available, and discussed the merits of the more important clinical instruments. It has been pointed out that investigations conducted with entirely different types of apparatus give consistent results and that in the viscosimeter we have a reliable clinical instrument comparable to the haemoglobinometer or haemocytometer. The only drawback to its more extended use, is the fact, that to get a proper appreciation of the viscosity reading, simultaneous estimations of the corpuscles and the haemoglobin must also be made.

The methods of employing the viscosimeter and the precautions to be observed in taking the blood samples have been described in full.

1./

1. As a preliminary to the study of blood viscosity in disease, a large number of normal cases were examined to fix standards for comparison. It was found that the blood viscosity, like the other figures given by the blood, varies with the age of the subject, rising to a maximum in middle life and then receding. I found the average viscosity in males to be 5.21 and that in females a little lower.

The viscosity varies about 3% at different times of day just as the numbers of red and white cells alter in relation to meal times. Under similar conditions, the changes in blood viscosity from day to day over considerable periods are also negligible. A standard viscosity exists for each person so long as he maintains a uniform state of health.

2. An effort was next made to find out by analysis of the clinical material what factors control the blood viscosity.

I have shewn that the viscosity of the blood bears a very close, but not a slavish, relationship to the number of the red cells, to their total volume in the fluid, to the percentage of haemoglonin and also to the specific gravity of the blood. The fact that discrepancies do occur, proves/

proves that other factors are at work.

3. A comparison of the blood viscosity and the blood "alkalinity" yielded no information.

4. It has been shewn that the viscosity is higher in venous blood and that in patients with cyanosis the viscosity of the capillary blood is also increased, in some cases to a very considerable degree so that at times the reading may be twice the normal.

The raising of the viscosity that follows increase in the carbon dioxide content, was also demonstrated in vitro.

5. The concentration of the plasma resulting from muscular exercise, hot air baths, persistent vomiting or diarrhoea produces an augmentation of the blood viscosity, while the dilution of the plasma accompanying renal or cardiac oedema and that following venesection, gives a reduction of the readings for the whole blood. These alterations in the composition of the plasma also affect the number of the red cells per c.m.m. and do not give a true picture of the influence of the fluid portion on the viscosity of the whole.

6./

6. A relationship of the number of white cells to the blood viscosity was also carefully looked for, but our examination leads us to believe that within ordinary pathological limits, the influence of the leucocytes is infinitesimal. It is true that high or low white counts were often associated with corresponding changes in the blood viscosity, but this depended rather on the anaemia or the fever present in these cases.

7. A large number of comparative observations were made on the "coagulation time" of the blood. No constant relationship to the viscosity could be discovered, though some of the low viscosity cases shewed very long "coagulation times".

8. In a schema where conditions can be kept constant, a rise in the viscosity of the fluid is accompanied by an increase in the pressure. In health the body can compensate in various ways, for alterations in blood viscosity and so keep the blood pressure uniform, but in some diseases this compensation is less perfect.

It has been pointed out that in normal people the two series of figures mount together as age advances till middle life is reached, when they diverge. The continued rise in the blood pressure reading is largely due to changes in vascular resistance,/

resistance, rather than to an actual increase in the intravascular pressure.

9. The clinical material has been examined from several points of view to study the relationship of these body constants. The most satisfactory arrangement was to group the cases under nine different headings according to whether the results were high, low, or normal. It was then found that certain diseases separated themselves into definite groups.

For example.-

Cases with Cyanosis shewed	V+ , and	B.P.+ .
Pulmonary insufficiency cases	V+ ,	B.P. -.
Hydraemias (renal insufficiencies)	V -,	B.P.+ .
Anaemias	V -,	B.P. -.

Cases of nephritis occurred in several of the groups according to the presence or absence of oedema and the height of the Blood pressure.

10. A possible connection between blood viscosity and pulse rate was also looked for, and it was shewn that any marked departure from the normal viscosity led to an increase in the rate of the heart beat either to maintain the blood pressure or to keep the thickened fluid in motion.

11. The respiratory rate did not shew any similar relationship to the blood viscosity.

12. Analysis of some sixty cases suffering from fever, proved that the rise of temperature was usually associated with an increase in the viscosity of the blood (in spite of the fact that in vitro the viscosity of a fluid falls rapidly as its heat increases.) This alteration cannot be due alone to loss of fluid by perspiration, since cases with the same temperature and the same amount of sweating may have widely different viscosities. It is probable that it depends rather on some product of altered metabolism (an acid perhaps) which acts by modifying the affinity of the cells for water and so changing the distribution of fluid in the body.

13. Before describing the laboratory experiments a short review was given of the factors which influence the viscosity of various disperse systems including colloids.

14. It has been shewn that the different protein fractions of the plasma have different viscosity values, euglobulin is the highest and serum albumin the least viscous while pseudoglobulin occupies an intermediate position.

15. The influence of the plasma viscosity on the total viscosity was examined by adding equal amounts/

amounts of corpuscles to gum solutions of different strengths and it was shewn that the viscosity of the plasma controls that of the whole blood, the two figures increasing in direct proportion.

16. Where the composition of the plasma remains unchanged the viscosity of the blood depends on the aggregate volume of the corpuscles present. At lower range, increasing percentage of R.B.C. is accompanied by a linear increase in the viscosity which can be expressed by the formula of Hatschek $V^{o} = V\ (1 + 4.5\ F)$.

At higher concentrations, the viscosity rises much more rapidly than the corpuscular volume and corresponds to the formula

$$V^{o} = V \quad \frac{\sqrt[3]{A}}{\sqrt[3]{A} - 1}$$

17. It has been shewn that any alteration in the saline concentration of the plasma is accompanied by a disturbance of the viscosity so that the normal 0.9% is the least viscous solution. The increased viscosity with hypotonic solutions is due to swelling of the corpuscles and that in hypertonic solutions to the increased friction produced by crenation (although the bulk of the plasma/

plasma in this latter case is actually increased.)

18. The great increase of viscosity which follows haemolysis of the corpuscles has also been demonstrated.

19. Minute quantities of acid added to blood mixtures in vitro greatly raised the viscosity. This at first is due to the cells imbibing water and swelling, and later depends upon the liberation of haemoglobin from the red corpuscles.

20. Very much larger quantities of alkali can be added to similar mixtures of blood without appreciably altering the viscosity of the fluid.

21. The effect of substituting various salts for the sodium chloride in mixtures containing washed corpuscles, has been investigated. A negative viscosity was produced by potassium iodide, potassium bromide and potassium thiocyanate. No change in viscosity occurred when sodium bicarbonate, sodium fluoride or potassium nitrate were employed; while potassium chloride, potassium chlorate, sodium carbonate and sodium phosphate actually increased the viscosity of the mixtures.

22. My clinical cases have been arranged under headings/

headings and have been examined to see if any disease is associated with characteristic changes in blood viscosity. Some interesting results have been recorded.

23. Cases of anaemia usually have a low viscosity which corresponds with the diminution of red cells and haemoglobin.

The picture given by the secondary anaemias most closely resembles the results found in artificial mixtures of corpuscles in serum, since in them the colour index tends to remain in the neighbourhood of one.

Cases of pernicious anaemia shewing the same degree of viscosity as the above cases, always have a much lower red cell count and a higher amount of haemoglobin, while under similar conditions the blood in chlorotic subjects contains many more erythrocytes but much less haemoglobin.

24. It is suggested that the low viscosity of the blood in anaemias at least partly accounts for the low blood pressure, the increased pulse-rate, for the palpitation and possibly for the haemic murmurs found in these cases.

25. Several of the cases quoted illustrate the improvement that occurs in the viscosity of the/

the blood under the administration of iron or of arsenic.

26. In heart cases where compensation is good the blood viscosity remains quite normal. Some cardiac patients however, have a certain amount of compensatory polycythaemia, and the viscosity in them is therefore above normal.

This state of affairs is almost always found in cases of mitral stenosis and congenital heart lesions.

27. Heart failure with oedema is accompanied by a diminished viscosity, which suggests that in these cases the blood is diluted.

28. In cases of heart failure without oedema the slowing of the stream in the systemic and pulmonary capillary areas, leads to cyanosis and an increase in the blood viscosity.

Some of the highest viscosity values were got in such patients where there was heart failure and cyanosis but no oedema.

29. The same remarks are also true in non-valvular cardiac cases.

30. The rapid improvement in the blood viscosity that follows the giving of heart tonics, is well seen in some of the tables.

31. Vascular degeneration and hypertrophy of both sides of the heart are likely to follow prolonged hyperviscosity of the blood, though the blood viscosity may have returned to normal long before arterio-sclerosis manifests itself.

A number of my arterio-sclerotic and aneurism patients did shew a high blood viscosity but in some of them it was obviously due to mild cyanosis.

32. In a series of cerebral haemorrhage cases the findings were similar. (A case of middle meningeal haemorrhage in a young man offered a sharp contrast to these.)

33. The prolonged reduction of blood viscosity produced by venesection is illustrated in several hemiplegia cases.

34. The majority of my patients with renal disease had a blood viscosity well below the normal. This hypo-viscous group included all the acute cases and such older cases as were suffering from a fresh exacerbation of the disease. All had more or less oedema and in most of them (not all) the quantity of urine secreted in 24 hours, was small. The reduction in the blood viscosity is at first due to a hydraemia but later this gives place to a true anaemia which tends to counteract the concentrating/

concentrating effect of hot air baths and diuretics.

35. The remaining renal cases who shewed no acute symptoms, had viscosity readings normal or slightly raised. The cardiac hypertrophy found in Bright's disease is not due to hyperviscous blood.

36. The findings in respiratory cases depend on the disease present. A relatively high viscosity is always found in pneumonias, while acute pleurisies with the same temperature and the same amount of perspiration shew much less change.

37. The viscous blood of chronic bronchitis depends on the dyspnoea and cyanosis present.

38. A fair proportion of ambulant phthisis cases have an increased blood viscosity which is not so commonly seen in other cases of tuberculosis.

39. In Malignant Disease the low viscosity values correspond to the accompanying anaemia.

40. Four cases of jaundice due to neoplasm shewed a diminished blood viscosity while a case of Hanot's cirrhosis with much jaundice gave a greatly augmented figure.

41. In a variety of gastric conditions the viscosity was found to be low as a result of haemorrhage or malnutrition. One haematemesis case gave a very/

very high reading after vomiting for several days.

42. Little characteristic change was found in patients suffering from diseases of the nervous system, but there was a definitely raised viscosity in some cases with acute meningitis.

43. The blood viscosity was low in cases of rheumatic fever in spite of the pyrexia and perspiration. This is especially true of uncomplicated cases, for with the onset of pericarditis an increase in the viscosity occurs.

44. In diabetics, high, medium and low readings were obtained and the results did not depend on the amount of urine excreted or on the percentage of sugar it contained.

45. All the thyroid cases, - exophthalmic, adenomatous and myxoedematous alike - shewed anaemia and a diminished blood viscosity.

46. A small group of Beri-beri patients had hypoviscous blood according to the degree of oedema they shewed, and some cases of scurvy had viscosities which corresponded to the richness of the blood in corpuscles.

To/

To sum up -

The blood viscosity depends on the number of the corpuscular elements present, and on the viscosity of the plasma. It is rapidly altered by conditions which concentrate or dilute the fluid of the blood, and is very sensitive to slight variations in the carbon dioxide. Such changes are readily neutralised in health, but under disease conditions persistent alterations of the blood viscosity frequently occur. It is probable that many of the symptoms found in such cases, may be directly attributable to the altered blood viscosity.

For a proper understanding of the physics of the circulation it is essential to have a knowledge of the part played by blood viscosity, and of the modifications it may undergo in disease.

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